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An Air Operations Division Live, Virtual, and Constructive (LVC) Corporate Interoperability Standards Development Strategy

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ABSTRACT

Today's simulation technology allows warfighters to participate in a continuous training cycle to maintain a high state of combat readiness by using cost-effective simulation alternatives in conjunction with live-fly operations and training missions. In the USA current development of Live, Virtual, and Constructive (LVC) systems for training and mission rehearsal and the rapid advancement of networking technologies and protocol standards/architectures have contributed to a synthetic environment where multi-force Distributed Mission Operations (DMO) joint/coalition exercises have become an everyday reality.

For the ADF to participate in such a capability corporate interoperability standards, processes, common applications and databases need to be developed. This report discusses a strategy to enable the ADF to begin to progress towards such a highly interoperable, LVC synthetic environment where a first important step is the development of a suitable set of ADF corporate LVC interoperability standards.

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Executive Summary

Today's simulation technology allows warfighters to participate in a continuous training cycle to maintain a high state of combat readiness by using cost-effective simulation alternatives in conjunction with live-fly operations and training missions. In the US current development of Live, Virtual, and Constructive (LVC) systems for training and mission rehearsal, and the rapid advancement of networking technologies and protocol standards/architectures have contributed to a synthetic environment where multi-force Distributed Mission Operations (DMO) joint/coalition exercises have become an everyday reality.

Recently the US DoD Live-Virtual-Constructive Architecture Roadmap (LVCAR) Study was completed. The purpose of this study was to develop a future vision and supporting strategy to achieve significant interoperability improvements in LVC simulation environments.

The LVCAR Study concluded that the best way forward is to enhance the interoperability of mixed-architecture events, while preserving options and positioning the community for some degree of architecture convergence in the future. These objectives are founded on the idea that having multiple architectures available for use is desirable and that the best way forward is to take actions that can reduce or eliminate barriers to interoperability between existing architectures and protocols. This strategy acknowledges that the existing architectures have been created, are evolving, and are being maintained to meet the specific needs of their constituent communities. Elimination of any architecture should only occur as a natural result of disuse. Modification and management of the existing architectures are left to the owning communities as the best option to ensure meeting the needs of the various user communities, both throughout the US DoD and amongst coalition partners. To resolve interoperability problems, efforts should be directed towards creating and providing standard resources, such as common gateways, common componentised object models, and common federation agreements. These can

resolve problems identified and render integration of the multiple architectures through an efficient and nearly transparent process by creating the perception of a single architecture that supports all of the diverse simulation systems. Thus, the systems will actually be serviced by an "architecture of architectures", comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

This report discusses a strategy to enable the ADF to begin to progress towards such a highly interoperable, LVC synthetic environment where a first important step is the development of a suitable set of ADF corporate, LVC interoperability standards.

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Dr. Lucien Zalcman has a Ph.D. in Experimental Physics from Melbourne University and a Graduate Diploma in Computing Studies from the Royal Melbourne Institute of Technology.

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Jon Blacklock joined the Royal Australian Air Force as an Air Defence Officer in 1978.

Postings followed as a fighter controller, as a Space Operations Senior Director and Combat Crew Commander in the US Defense Support Program supporting nuclear non-proliferation and missile early warning systems. Staff tours were completed as Project Manager for the ADF Air 5077 Airborne Early Warning & Control Project, and in ADF HQ as requirements manager.

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Contents

Acronyms and Abbreviations

AAR	After Action Review
ABM	Air Battle Management
ACMI	Air Combat Manoeuvring Instrumentation
ADF	Australian Defence Force
ADGE	Air Defence Ground Environment
ADGESIM	Air Defence Ground Environment SIMulator
ADS	Advanced Distributed Simulation
AEW&C	RAAF Airborne Early Warning & Control
AOD	DSTO's Air Operations Division
AOSC	DSTO's AOD Air Operations Simulation Centre
API	Application Programmers Interface
AWACS	Airborne Warning and Control System
BOM	(HLA) Base Object Model
CCD	Capability Concept Demonstrator
CGF	Computer Generated Forces
CoA	Course of Action
ConOps	Concept of Operations
COTS	Commercial-Off-The-Shelf
CTIA	(US Army's) Common Training and Instrumentation Architecture
DACS	ASTi Digital Audio Communications System
DACS	(AOD's AOSC) Deployable Aircraft Cockpit Simulator
DIS	Distributed Interactive Simulation
DMO	Distributed Mission Operations
DSTO	Defence Science and Technology Organisation
DTE	Distributed Test Event
DoD	US Department of Defence
ESG	Environment Scenario Generator
FEDEP	(HLA) Federation Development and Execution Process
FOM	(HLA) Federation Object Model

GIG	Global Information Grid
GOTS	Government-Off-The-Shelf
HIL	Human-In-the-Loop
HLA	High Level Architecture
IEEE	Institute of Electrical and Electronic Engineers
IFF	Identify Friend or Foe
IP	Internet Protocol
JFCOM	(United States DoD) Joint Forces Command
JJTTCP	Norwegian Joint Tactical Training Capability Prototype
JREAP	Joint Range Extension Application Protocol
JTIDS	Joint Tactical Information Distribution System
LVC	Live-Virtual-Constructive
LVCAR	Live-Virtual-Constructive Architecture Roadmap
MASC	UK Ministry of Defence NITEworks Maritime Airborne Surveillance and Control
MATREX	Modeling Architecture for Technology, Requirements and Experimentation
MIDS	Multifunctional Information Distribution System
M&S	Modeling & Simulation
MSCT	Multi-Source Correlator/Tracker
MTDS	UK Ministry of Defence (i.e. RAF) Mission Training through Distributed Simulation
MTC	Mission Training Centre
NATO	North Atlantic Treaty Organization
NCW	Network Centric Warfare
NMSSP	NATO Modelling and Simulation Standards Profile
OMT	(HLA) Object Model Template
PDU	DIS Protocol Data Unit
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
RFT	Request For Tender
RPR-FOM	(HLA) Real-time Platform Reference Federation Object Model

RTI	(HLA) Runtime Infrastructure
SAF	Semi Automated Forces
SATCOM	Satellite Communications
SEDRIS	Synthetic Environment Data Representation and Interchange Specification
SIMPLE	Standard Interface for Multiple Platform Link Evaluation
SISO	Simulation Interoperability Standards Organization
SOA	Service Orientated Architecture
SOM	(HLA) Simulation Object Model
STANAG	NATO STANdardization AGreement
TDL	Tactical Data Link
T&A	Test and Acceptance
TENA	Test and Training Enabling Architecture
USAF	US Air Force
USJFCOM	US Joint Forces Command
USN	US Navy
UDP	User Datagram Protocol
VoIP	Voice over IP
VMF	Variable Message Format
WIRE	(RAAF/DSTO) Wedgetail Integration and Research Environment

1. Introduction

Today's modern simulation technology allows war-fighters to participate in a continuous training cycle and maintain a high state of combat readiness by using cost-effective simulation alternatives in conjunction with live-fly operations and training missions. Current development of live, virtual, and constructive (LVC) systems for training and mission rehearsal, the rapid advancement of networking technologies and protocol standards/architectures such as Distributed Interactive Simulation (DIS) [DIS (1995)], [DIS (1998)] and High Level Architecture (HLA) [HLA (2000)-1], [HLA (2000)-2], [HLA (2000)-3], [HLA (2003)] have all contributed to an environment where highly-distributed training, mission rehearsal, operations support, and multi-force Distributed Mission Operations (DMO) joint/coalition exercises have become a reality [Portrey].

1.1 An AOD Mission Training Centre, Capability Concept Demonstrator

In the Australian Defence Force (ADF) the RAAF does not yet use LVC interoperability.

In a recent DSTO report [Zalcman (2010)] an Air Operations Division (AOD) Mission Training Centre, Capability Concept Demonstrator (AOD MTC CCD) programme, similar to that developed by the UK MOD Mission Training through Distributed Simulation (MTDS) programme, was proposed.

The objectives of such an AOD MTC CCD programme will be

- To study various elements of Joint and Coalition, Live-Virtual-Constructive (LVC), Synthetic Range training to provide guidance on technical and operational issues to assist the RAAF to migrate towards a highly interoperable, LVC corporate synthetic environment (Synthetic Range) to assist and enable the RAAF to develop a training focused, DMO compliant RAAF Mission Training Centre capability;

- To do experimentation, research and development to help the ADF and RAAF develop corporate interoperability standards that are compliant with USAF DMO standards. These standards (the Synthetic Range Interoperability Model) will form the advanced distributed simulation infrastructure (ie a standards based approach) upon which the AOD MTC CCD (and eventually the RAAF MTC) will be developed. This work can then be used to reduce risk and cost when acquiring future ADF LVC components, training systems and operational platforms with LVC capabilities; and

- Test, evaluate and/or develop re-usable LVC Mission Training Centre components (Blue, Red and White Forces Computer Generated Forces (CGF) applications, Loggers, After-Action-Review applications, Situation Awareness applications, etc) which could be used (ie re-used) to reduce cost and risk for current and future ADF and RAAF training systems and future operational platforms with LVC interfaces.

1.2 The USA DoD Live-Virtual-Constructive Architecture Roadmap Study

The report proposing the AOD MTC CCD programme [Zalcman (2010)] was produced before the recent release of the USA DoD Live-Virtual-Constructive Architecture Roadmap (LVCAR) Study [LVCAR-1], [LVCAR-2]. The purpose of this LVCAR study was to develop a future vision and supporting strategy to achieve significant interoperability improvements in LVC synthetic environments. To support the implementation of this strategy the LVCAR study specifies near-, mid-, and long-term actions that collectively delineate a roadmap to guide the evolution from the current state of LVC environment development and achieve the desired future vision. The Roadmap addresses three main areas of concern: the desired future integrating architecture(s); the desired business model(s); and the manner in which standards should be evolved and compliance evaluated.

The LVCAR Study concluded that the best way forward is to enhance the interoperability of mixed-architecture events, while preserving options and positioning the community for some degree of architecture convergence in the future. This strategy acknowledges that existing architectures have been created, are evolving, and are being maintained to meet the specific needs of their constituent communities. Efforts should be directed towards creating and providing standard resources, such as common gateways, common componentised object models, and common federation agreements. This will create the perception of a single architecture that supports all of the diverse simulation systems where systems will actually be serviced by an "architecture of architectures", comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

1.3 The Concept of the Synthetic Range and the Synthetic Range Interoperability Model

The Concept of the Synthetic Range, and its associated Synthetic Range Interoperability Model, has been previously reported in DSTO Reports and conference papers (see [Zalcman (2010)]). The Concept of the Synthetic Range and the Synthetic Range Interoperability Model support the conclusions and recommendations of the LVCAR Study and these conclusions and recommendations are discussed in this current report.

For the ADF to participate in multi-force Distributed Mission Operations (DMO) joint/coalition exercises, ADF corporate interoperability standards, common applications, processes and databases need to be developed. This report discusses a strategy to enable the ADF to begin to progress towards a highly interoperable, LVC synthetic environment where a first important step is the development of a suitable set of corporate LVC interoperability standards.

1.4 How This Report is Structured

The Concept of the Synthetic Range and the Synthetic Range Interoperability Model that provide a simplified way of understanding how military Live, Virtual and Constructive (LVC) systems can interoperate are discussed in section 2 of this report.

Section 3 defines and discusses in detail the three main types of Synthetic Range systems (ie Live, Virtual and Constructive (LVC) systems), and the main, commonly used LVC Synthetic Range system interoperability protocols/standards such as DIS, HLA, RPR-FOM, TENA, SIMPLE, SISO-J, and JREAP.

The recently released US DoD LVC Architecture Roadmap (LVCAR) Study is discussed in section 4, and the relevance and applicability of this study to DSTO and the ADF is discussed in section 5.

Section 6 discusses what LVC interoperability standards are used in coalition nations including modeling and simulation interoperability standards recommended by NATO.

Section 7 discusses reducing the LVC interoperability model further to a more cost-effective corporate interoperability model that can be applied to ADF simulation (ie Virtual and Constructive) systems.

How we use the findings of the US DoD LVCAR Study to proceed to develop a corporate ADF Synthetic Range Interoperability Model is discussed in section 8.

Sections 9 and 10 discuss compliance with a Synthetic Range Interoperability Model and exactly what needs to go into the beginnings of an ADF corporate Synthetic Range Interoperability Model.

Section 11 presents some DSTO work programmes that could be used to continue development of the Corporate ADF, Synthetic Range Interoperability Model and how this work can then be used to develop a proposed USAF Distributed Mission Operations compliant training system for the RAAF that would begin to transform how the RAAF would do its future training.

Conclusions and recommendations are presented in sections 12 and 13.

1.5 Section Summary

In summary:

- **What Are We Doing** - We are discussing and developing a strategy to produce a set of minimalistic, but precise and unambiguous, corporate LVC interoperability standards to progress towards a highly interoperable, RAAF, LVC synthetic environment;
- **Why Are Doing This** - To move from reducing risk towards guaranteeing LVC interoperability. You can never guarantee 100% interoperability but the objective of developing a set of corporate LVC interoperability standards is to reduce risk and to also move towards guaranteeing a useable level of out-the-box interoperability for

compliant LVC systems when they are delivered to, and accepted by, the Commonwealth. ADF/RAAF high-fidelity training simulators may cost between $50 and $150 million. Often these training simulators cannot interoperate, even though they were specified to have an advanced distributed simulation capability. However they may not have been specified appropriately. Once an appropriate set of minimalistic, but precise and unambiguous, corporate LVC interoperability standards have been developed, a corresponding set of associated Request for Tender (RFT) specifications and Test and Acceptance procedures can also be developed. ADF LVC systems that are compliant with these RFT specifications will be delivered to and, once appropriate compliance testing has been done, accepted by the Commonwealth with a useable level of out-the-box LVC interoperability. Such a **standards based approach** will reduce cost and risk to the Commonwealth; and

- **How Are We Doing This** – This report discusses and develops a strategy that shows exactly how a set of precise and unambiguous, corporate LVC interoperability standards can be produced. Appropriate Test and Acceptance procedures and RFT specifications should then also be developed.

2. The Concept of the Synthetic Range

The Concept of the Synthetic Range, and its associated Synthetic Range Interoperability Model, provide a simplified way of understanding how military Live, Virtual and Constructive (LVC) systems (see section 3) can interoperate.

Large-scale, operational (ie Live) exercises provide opportunities to train crews in team and inter-team skills. However cost, fatigue life concerns, range site capabilities, weather, and frequency of event limitations make this only a partial solution to crew readiness training. A significant gap exists between training obtained using stand-alone simulators and training obtained during live training exercises for combat crews. Alternative training methods, such as Synthetic Range, LVC training (eg USAF DMO Virtual Flag training exercises), should be considered to cost-effectively maintain crew readiness [Blacklock (2007)], [Zalcman (2010)].

Such alternative training methods would allow LVC players at multiple sites to participate in synthetic environment training exercises ranging from individual and team participation to full theatre-level battles. Advantages arise such as increased value and efficiency of actual operational platform hours, improved communication skills in a joint and coalition environment, and an increased sense of trust and confidence amongst participants [Cochrane].

Simulation, when combined with a competency-based training program and live-flying training, can narrow the gap between continuation training and combat mission readiness [Portrey].

2.1 What Is A Synthetic Range?

Synthetic range LVC systems can interoperate over a local and/or wide area network in a common virtual synthetic environment no matter where these systems are geographically located throughout the world.

Synthetic Range systems can share the same common ("ground truth") scenario on an advanced distributed simulation network.

In a synthetic (LVC) range the entirety of the test and training event will be represented in a synthetic environment where the location of the entities in the synthetic environment may bear no relationship to the real, geographical location of the participating LVC systems.

According to Daly et al. [Daly]

> *"Synthetic environments are simulations that represent activities at a high level of realism. These environments may be created within a single computer or over a distributed network connected by local and wide area networks and are augmented by realistic special effects and accurate behavioral models. They allow visualisation of, and immersion into, the environment being simulated"* [US].

2.2 What Is A Synthetic Range Interoperability Model?

A *Synthetic Range Interoperability Model* simplifies the development of a synthetic range architecture and thus the integration of participating Synthetic Range compliant, LVC systems.

An appropriate set of ADF corporate, synthetic range, interoperability standards is being developed to enhance capability and reduce risk and cost. Once such a set of Synthetic Range Interoperability Model standards has been developed, a set of complementary test and acceptance procedures can also be developed [Ross].

The Synthetic Range Interoperability Model (Figure 1) addresses interoperability from three points of view:

- Advanced Distributed Simulation interoperability;
- Tactical Data Link interoperability; and
- Radio Communications interoperability.

Sharing a common scenario (ie the Ground Truth) on an advanced distributed simulation network in a LVC Synthetic Environment will reduce costs considerably by not requiring real operational platforms for every entity in a common scenario. The potential of this approach was demonstrated in Australia in 2007 with LVC participants from the US and ADF participating in Exercise Talisman Sabre 07. Further savings may be achieved by building distributed (and re-usable) system capability and functionality using smaller (but more dedicated) distributed simulation applications rather than creating a single large LVC software system. The DSTO developed Air Defence Ground Environment SIMulator (ADGESIM) RAAF trainer [Blacklock (2006)], [Blacklock (2007)], [Zalcman (2005)], [Zalcman

(2006)], [Zalcman (2008)] uses such a distributed architecture and the ADGESIM applications are actually stand-alone, independent applications that can be reused in other DIS LVC simulation systems.

Supporting real (ie Live) Tactical Data Links realistically simulates the real world Network Centric Warfare (NCW) environment and enhances the fidelity and capabilities of Synthetic Range multi-player, multiple site exercises.

Voice communication is the common variable tying LVC entities together regardless of the operating domain - it is a basic component of the synthetic battle space [Rumpel].

Note that the architecture / interoperability model (Figure 1 and Table 3) is a *minimalistic* starting point - it does not preclude later enhancement of the current components or addition of other new components to the model (ie the ADF model) or to a specific version of the model (eg a RAN Synthetic Range Interoperability Model) (see section 9.4).

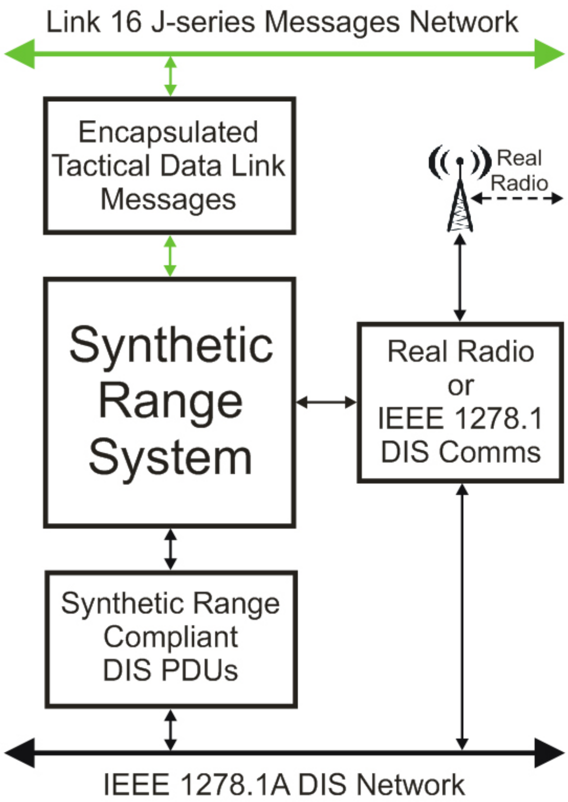

Figure 1 The (Generic) Synthetic Range Interoperability Model.

The long term research and development objectives of the Synthetic Range are to:

- Further develop the Concept of the Synthetic Range;
- Develop corporate (ie recommended ADF) Synthetic Range Interoperability Model interoperability standards; and

- Ensure (through Australian Defence Simulation Office / Defence Materiel Organisation participation) that in future every LVC system that may need to interoperate is acquired with a set of common Synthetic Range Interoperability Model capabilities (ie Gateways/capabilities) that comply with ADF corporate interoperability standards to enable a common level of LVC interoperability at the time of "out-the-box" system delivery and acceptance by the ADF.

2.3 Section Summary

The concept of the Synthetic Range and the Synthetic Range Interoperability Model have been discussed. The Synthetic Range Interoperability Model views LVC interoperability from three points of view:

- Advanced Distributed Simulation interoperability;
- Tactical Data Link interoperability; and
- Radio Communications interoperability.

The objective of this work is to continue development of an ADF Corporate Synthetic Range Interoperability Model (ie a set of ADF Corporate interoperability standards) that will precisely and unambiguously define LVC interoperability parameters that will be specified when acquiring any ADF LVC system. Any such system that complies with the recommended (ie specified) ADF Corporate Synthetic Range Interoperability Model should be delivered and accepted (ie tested) with a useful, usable, out-the-box level of LVC interoperability.

Such an ADF Corporate Synthetic Range Interoperability Model will result in reduced cost and risk to the ADF for compliant ADF LVC systems.

3. Live-Virtual-Constructive INTEROPERABILITY

3.1 Live-Virtual-Constructive System Types

A synthetic range system can be broadly classified as belonging to one of three different types of systems - Live, Virtual, or Constructive (LVC) [Zalcman (2010)] where:

3.1.1 Live Systems

- Live systems -
    - Live systems are "instrumented" real-world, operational military platforms. Instrumentation (Embedded or On-Board-Training-Systems, Air Combat Manoeuvring Instrumentation (ACMI) systems [Cubic], etc) attached to these Live systems can provide information such as location, speed, acceleration, system orientation, weapon status, etc. to the synthetic range distributed

simulation network in real-time such that this data can interoperate in the synthetic range virtual environment. Live system data may need to be distributed via radio telemetry to a dedicated, ground station where it is distributed to other synthetic range participants using standardised, simulation network protocols. In the same way, data from other synthetic range participants must be converted from the standardised simulation network protocols and provided in an appropriate form to the Live, synthetic range compliant systems;

- ➢ Live training exercises real people using real equipment in a real environment; and

- ➢ Live Simulation involves real people operating real systems [NATO M&S Vision]. The Navy conducts this type of training at sea using steaming hours while ships are under way. Daly at al. [Daly] differentiate between Synthetic training (delivery method) that occurs with real people using real equipment in a virtual environment, and Live training that occurs using the same real people and the same real equipment but Live training occurs in the real environment not a virtual environment.

3.1.2 Virtual Systems

- Virtual systems -

  - ➢ Virtual systems comprise training and experimentation simulators (Human-In-the-Loop (HIL) simulators) that are crewed by people. These systems may have advanced distributed simulation capabilities that use simulation network protocols. However some form of common connection gateway device may be required to convert the simulation system protocols to (required) corporate standard, synthetic range, interoperability protocols;

  - ➢ Virtual training exercises real people using simulated equipment in a simulated environment; and

  - ➢ Virtual Simulation involves real people operating simulated systems. Virtual training usually involves wargaming in-house (in a building) using simulation equipment.

3.1.3 Constructive Systems

- Constructive systems -

  - ➢ Constructive systems are entirely synthetic representations of both platforms and people - they act according to software rules rather than through human direction;

  - ➢ Constructive training exercises simulated people using simulated equipment in a simulated environment. Constructive Modeling or Simulation involves simulated people operating simulated systems [NATO M&S Vision]. It is the most "artificial" of all active (i.e., non-classroom) training and it involves only the practical application of cognitive skills; and

- Constructive training can include personal computer (PC) or tabletop wargaming. This training focuses primarily on strategic, operational, or tactical decision-making.

The commonly used definitions of Live, Virtual and Constructive Synthetic Range systems are shown in Table 1.

To achieve interoperability among LVC systems within a common scenario requires compliance with an agreed set of interoperability standards including network infrastructure, data, interoperability protocols, platform/environment representation, etc [Aldinger], [Zalcman (2010)]. This requires the development of an interoperability model (the Synthetic Range Interoperability Model) that is a crucial part of the synthetic range architecture. All synthetic range systems that are compliant with this set of interoperability standards (ie the interoperability model) should be (highly) interoperable regardless of whether the systems are Live, Virtual or Constructive systems. How interoperable such systems are depends on the "completeness" of the interoperability model used.

Table 1 More Commonly Used LVC System Definitions.

- **Live** = real people in real locations using real equipment
- **Virtual Simulation** = real people in simulators
- **Constructive Simulation** = simulated entities in a simulated environment

A graphical representation of a LVC Synthetic Range environment is shown in Figure 2.

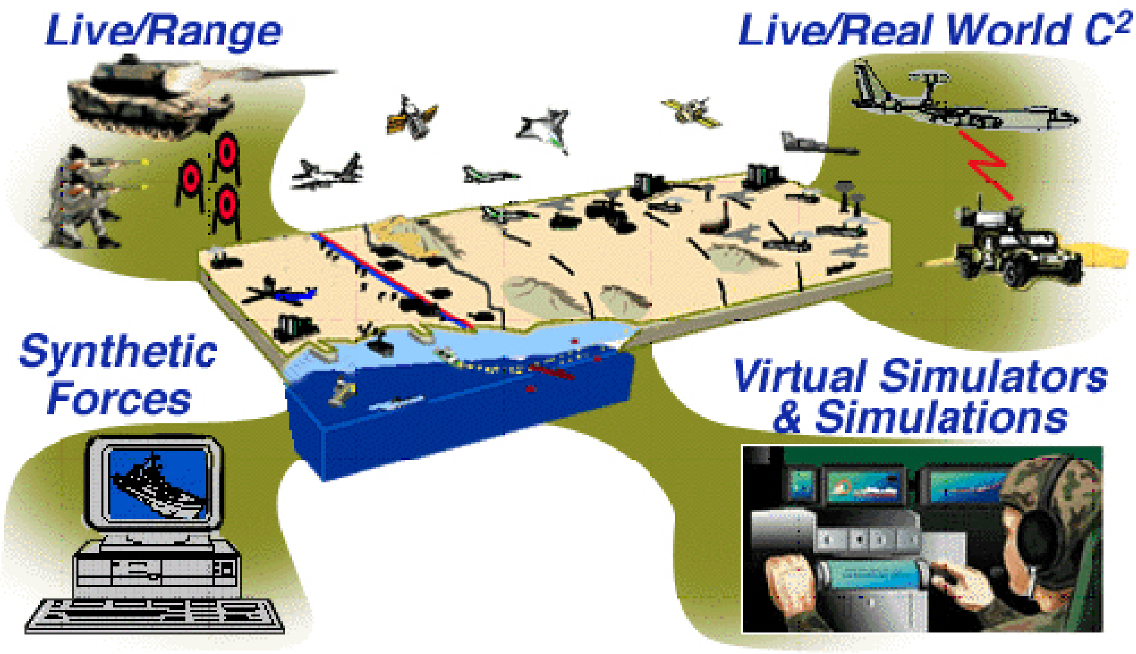

Figure 2 A Graphic of an LVC Synthetic Environment

Up till now most participants in distributed simulation exercises would normally only be expected to be Virtual or Constructive systems (ie nodes) however an appropriate strategy should consider full LVC interoperability (ie include Live platform interoperability).

3.2 LVC Interoperability Standards

The NATO Modelling and Simulation Standards Profile (NMSSP) defines interoperability among simulations (should be LVC systems) as

> *"The capability for simulations to physically interconnect, to provide (and receive) services to (and from) other simulations, to use these exchanged services in order to effectively work together. This definition refers mainly to "technical interoperability" that means the possibility to physically interconnect then communicate. A lot of additional work has to be done after interconnection is ensured, to reach higher levels of interoperability (semantic or substantive interoperability)"* [NATO NMSSP].

3.2.1 Distributed Interactive Simulation (DIS)

DIS - The NATO Modelling and Simulation Standards Profile describes DIS (IEEE 1278.1/A Distributive Interactive Simulation [DIS (1995)], [DIS (1998)]) as:

- DIS is an interoperability standard based on exchanges of formatted messages between simulation applications. Simulation state information and interactions are encoded in messages known as Protocol Data Units (PDUs) and are exchanged between hosts using existing transport layer protocols, though normally broadcast User Datagram Protocol (UDP) is used;
- More than 15 years of use in many NATO countries; very mature technology; and

- DIS is a protocol for linking simulations of various types at multiple locations to create realistic, complex, virtual worlds for the simulation of highly interactive activities. This protocol can be used to bring together systems built for separate purposes, technologies from different eras, products from various vendors, and platforms from various services, and permits them to interoperate. DIS exercises are intended to support a mixture of virtual entities with computer controlled behaviour (computer generated forces), virtual entities with live operators (human-in-the-loop simulators), live entities (operational platforms and test and evaluation systems), and constructive entities (wargames and other automated simulations). There are many operational implementations in various nations. The best example is the US Air Force Distributed Mission Operation (DMO) programme. The primary limitation of this standard is that it is applicable to only real time (simulated time = wall clock time) simulation and has a fixed object model defined at the platform level.

3.2.2 High Level Architecture (HLA)

The NATO Modelling and Simulation Standards Profile describes HLA (IEEE 1516 High Level Architecture [HLA (2000)-1], [HLA (2000)-2], [HLA (2000)-3]) as:

- The High Level Architecture (HLA) for M&S is defined by three technical documents. The standards contained in this architecture are interrelated and need to be considered as a product set, as a change in one is likely to have an impact on the others. As such, HLA is an integrated approach that has been developed to provide a common architecture for simulation;

- The Framework and Rules [HLA (2000)-1] is the capstone document for a family of related HLA standards. It defines the HLA, its components, and the rules that outline the responsibilities of HLA federates and federations to ensure a consistent implementation. The Federate Interface Specification [HLA (2000)-2] defines the standard services of, and interfaces to, the HLA Runtime Infrastructure (RTI). These services are used by the interacting simulations to achieve a coordinated exchange of information when they participate in a distributed federation. The Object Model Template provides a specification [HLA (2000)-3] for describing object models that define the information produced or required by a simulation application, and for reconciling definitions among simulations to produce a common data model for mutual interoperation;

- The High Level Architecture is a technical architecture developed to facilitate the reuse and interoperation of simulation systems and assets. The HLA provides a general framework within which developers can structure and describe their simulation systems and/or assets, and interoperate with other simulation systems and assets.

- The HLA consists of three main components:

  - The first component specifies the Framework and Rules;

  - The second component provides the interface specifications; and

  - The third component describes the Federation Object Model requirements in the Object Model Template (OMT) Specification;

- HLA is widely implemented within NATO and PfP (Partnership for Peace) nations. There are a variety of commercial, open source and government support tools; and

- HLA is not "plug and play". Some parts of the standards are left open to the RTI implementer, thus different RTIs are **not guaranteed to interoperate** (ie **<u>in most cases they will not interoperate</u>**).

3.2.3 The Real-time Platform-level Reference-Federation Object Model (RPR-FOM)

While the HLA Standards dictate how federates exchange data, it is a Federation Object Model (FOM) that dictates what data is being exchanged in a particular federation. HLA does not mandate the use of any particular FOM however several "reference FOMs" have been developed to promote a-priori interoperability. That is, in order to communicate, a set of federates must agree on a common FOM (among other things). Reference FOMs provide ready-made FOMs that are supported by a wide variety of tools and federates. Reference FOMs can be used as-is or can be extended to add new simulation concepts that are specific to a particular federation or simulation domain;

The NATO Modelling and Simulation Standards Profile describes the RPR-FOM Standard for **R**eal-time **P**latform-level **R**eference **F**ederation **O**bject **M**odel (SISO-STD-001.1-1999) [RPR-FOM-1] as:

- The RPR-FOM is a reference FOM that defines HLA classes, attributes and parameters that are appropriate for real-time, platform-level simulations. Applications that have previously used DIS (or would have considered using DIS), often use the RPR-FOM (or a derivative of it) when interoperating using HLA. The RPR FOM was developed by a SISO Product Development Group (PDG). Its goal was not to just implement the DIS Protocol Data Unit structures within HLA object and interaction classes, but rather to provide an intelligent translation of the concepts used in DIS to a HLA environment;

- A companion document, known as the GRIM (Guidance, Rationale, and Interoperability Mappings) provides documentation for the RPR FOM. This document is known as SISO-STD-001.1-1999 [RPR-FOM – 1.1];

- RPR-FOM 1.0 [RPR-FOM – 1] is based on the IEEE 1278.1-1995 [DIS (1995)] version of the DIS Standard and became a SISO standard in 1999. It corresponds to the US DoD NG 1.3 version of HLA.

- RPR-FOM 2.0 [RPR-FOM – 2] was to correspond to the IEEE 1278.1/A version of DIS [DIS (1998)]. However the SISO balloting process was never completed due to a lack of SISO contributors;

- Enables federations of real-time, platform-based simulations, typically allowing DIS users to achieve HLA compliance;

- Is in use in many HLA federations; and

- Limitations of this Standard: Mainly targeted to entity-level simulations.

3.2.4 The Test and Training Enabling Architecture (TENA)

The NATO Modelling and Simulation Standards Profile describes TENA (The Test and Training Enabling Architecture) as:

- TENA is a product of the Foundation Initiative 2010 (FI 2010) project, sponsored by the Central Test and Evaluation Investment Program. The core of TENA is the TENA Common Infrastructure, including the TENA Middleware, the TENA Repository and the TENA Logical Range Data Archive. TENA also specifies the existence of a number of tools and utilities, including those necessary for the efficient creation of a logical range. Range instrumentation systems (also called range resource applications) and all of the tools interact with the common infrastructure through the medium of the TENA object model. The TENA object model encodes all of the information that is transferred between systems during a range event. It is the common language with which all TENA applications communicate;
- Is widely used within the US range community and actively managed through an Architecture Management Team;
- Can be used for Live Range Interoperability, LVC Interoperability and Test Interoperability;
- The initial implementation for TENA is to interoperate with US National Test and Training Ranges. It has been used at USJFCOM to incorporate Live and Range assets into LVC Training exercises (see https://www.tena-sda.org/display/intro/ news for extensive listing of program usage); and
- Is currently targeted for real-time applications only.

3.2.5 SIMPLE

The NATO Modelling and Simulation Standards Profile describes SIMPLE (Standard Interface for Multiple Platform Link Evaluation - STANAG 5602) as:

- STANAG 5602 (SIMPLE) provides specifications for a common standard to interconnect ground rigs of all types (e.g. simulation, integration facilities etc.) for the purpose of Tactical Data Link (TDL) Interoperability testing;
- SIMPLE supports DIS (but not HLA) by:
    - Enabling DIS PDUs to be encapsulated and distributed around a SIMPLE network within the SIMPLE protocol packets: and
    - DIS can be used to stimulate SIMPLE systems for testing purposes;
- The second version of SIMPLE was promulgated in 2006 and the next version (edition 3) is under ratification. The standard is evolving thanks to feedback coming from a large base of users;
- The SIMPLE STANAG (5602) specifies the requirements for transfer of data between remote sites in different locations to support interoperability testing of TDL implementations in the different platforms of NATO Nations and Organisations;

- Is used in NATO; and
- Is not fully/only targeted to simulation interoperability. It was not originally designed to model Link-16 for training, but for testing only. The standard does not model all Link-16 capabilities, such as net entry, net exit, perceived versus actual position, Link-16 relay, message encryption, and Time Slot Reallocation. It is applicable to real-time simulation applications.

3.2.6 SISO-J

The NATO Modelling and Simulation Standards Profile describes SISO-J (Tactical Data Information Link - Technical Advice and Lexicon for Enabling Simulations - referred to as SISO-STD-002-2006) [SISO-STD-002-2006] as:

- There are immediate operational requirements for existing military simulations to exchange Link-16 data using a single interoperability standard. The purpose of this standard is to meet this need by providing a standard for simulating the Link-16 protocol. This standard defines five fidelity levels, from message exchange only to Link-16 network modelling, including Return Trip Timing messages, Net Entry and Exit, Actual versus Perceived location, and encryption methods. The SISO Link-16 standard interoperates in DIS using the Transmitter and Signal PDUs, and in HLA under the equivalent BOM and RPR FOM paradigms;
- In use for some years by the US Air Force, Navy, and Marines for distributed simulation training;
- The main objective of the SISO-J protocol is to establish a standard for Link-16 message exchange and JTIDS (Joint Tactical Information Distribution System) network simulation in the DIS and HLA interoperability paradigms. The intent is to prescribe the content of the standard fields of the Transmitter and Signal PDUs (and the corresponding HLA RPR-FOM Transmitter Object and Signal Interactions) and establish procedures for their use. Compliance with these procedures facilitates interoperability among Link-16 simulation systems;
- Is in use in NATO and partner countries; and
- This standard applies only to Link-16/JTIDS/MIDS. It does not address Link-16 over satellite communications (SATCOM).

3.2.7 JREAP

The NATO Modelling and Simulation Standards Profile does not include the JREAP (Joint Range Extension Applications Protocol MIL-STD-3011) [MIL-STD-3011] standard. JREAP extends the range of Tactical Digital Information Links by permitting tactical data messages to be transmitted over long-distance networks. According to Wikipedia [Wikipedia]:

- JREAP was developed due to the need to communicate data over long distances without degradation to the message format or content. JREAP takes the message from its original format and changes the protocol so that the message can be transmitted over Beyond Line-of-Sight media;

- JREAP is the protocol and message structure for the transmission and reception of pre-formatted messages over communications media other than those for which these messages were designed;
- JREAP provides a foundation for Joint Range Extension (JRE) of Link-16 and other tactical data links to overcome the line-of-sight limitations of radio terminals such as the JTIDS and MIDS TDL communications systems, and extends coverage of these data links through the use of long-haul media;
- JREAP-A is an encrypted satellite link using a serial data interface to exchange information in a half-duplex or broadcast mode;
- JREAP-B is a secure synchronous or asynchronous point-to-point serial data interface used to exchange information in a full-duplex data-transparent mode; and
- JREAP-C is a secure data link interface that encapsulates JREAP over IP using IP based networks for the exchange of information.

3.3 Section Summary

The three main types of Synthetic Range systems (Live, Virtual and Constructive) have been defined and discussed.

Commonly used Synthetic Range LVC system interoperability protocols/standards (ie de-facto standard protocols such as DIS, HLA, RPR-FOM, TENA, SIMPLE, SISO-J, and JREAP) have also been defined and discussed in detail.

4. The USA DOD LVC Architecture Roadmap

4.1 Purpose and Scope of the USA DoD LVC Architecture Roadmap (LVCAR) Study

The purpose of the Live-Virtual-Constructive Architecture Roadmap (LVCAR) Study was to develop a future vision and supporting strategy to achieve significant interoperability improvements in LVC simulation environments. To support the implementation of this strategy the LVCAR study specifies near-, mid-, and long-term actions that collectively delineate a roadmap to guide the evolution from the current state of LVC environment development to achieve the desired future vision. The Roadmap addresses three main areas of concern; the desired future integrating architecture(s), the desired business model(s), and the manner in which standards should be evolved and compliance evaluated.

The LVCAR Roadmap is intended to be a living dynamic document, to stimulate a process of continual improvement to guide actions and decision-making on the development and employment of LVC environments across the DoD. For context and scope, this Roadmap sets the course for achieving the US DoD's vision for LVC integrating architectures over the next 10 years. Understandably, in a field dependent on technologies and processes from so many other organizations, mid-course adjustments are anticipated.

4.2 An Underlying and Fundamental Aspect of the Problem

According to the LVCAR Study documentation there is a perception by many in the LVC community that interoperability will be much easier (and less costly) if there was only a single architecture available for use. There would be benefit by eliminating the costs associated with maintaining multiple architectures with overlapping capabilities. The desire to achieve such a single-architecture state is based on a number of difficulties in the current situation that can be directly attributed to the existence of these multiple architectures [LVCAR-1].

First, problems arise whenever multiple architectures must be integrated for use in a single event. In many cases, such mixed-architecture events can only use the set of capabilities common across all of the architectures to be included in the event. This is sometimes described as the "dumbing down" of the more capable architectures because the full range of unique capabilities they offer (e.g., more advanced capabilities such as repeatability, communications bandwidth efficiency, ownership transfer) cannot be used across the entire set of participating systems. Further, the costs required to integrate architectures rarely contribute directly to achieving simulation event goals. Instead, the associated costs usually provide point solutions, versions of which have likely been created in the past and probably will be paid for, and created, again in the future. Thus, the integration costs are viewed as recurring expenses that contribute little to achieving event goals and should thus be eliminated. Mixed architectures impede "plug-and-play". Mixed architecture events are more expensive to integrate, result in overall slower systems, and it is sometimes impractical (difficult) to construct simulation events using any of the wide range of assets (e.g., simulations, simulators, labs, ranges, C4ISR systems, etc.) available in the DoD inventory. In such events participating assets may not be chosen based purely on functional merit alone because systems may be constrained to be compatible with a specific architecture. If the "out-of-the-box" compatibility constraints are ignored, some amount of additional cost (time, dollars, etc.) often follows. Typically, such costs cannot be ignored, so events will be designed that only consider compatible systems.

However, while each of these disadvantages can be attributed to the existence and use of multiple architectures, their existence does not necessarily justify the assumption that ridding the DoD of all but one architecture would result in an optimal state of affairs. According to the LVCAR Study there are at least five main factors indicating that such an assumption appears to be fallacious. First, legacy systems will continue to be used and it is unlikely that these systems will upgrade to using a new or different architecture. Thus, use of legacy systems is most likely to preclude the possibility of ever achieving a truly "single-architecture" state. Second, use of a single architecture may still require the use of supporting bridges, much as use of different RTIs can require bridges today. Third, gateways will be required for connecting any single simulation architecture to C4I systems, to the GIG, or, in general, to any type of system that has a primary purpose outside of the simulation arena. Fourth, the alignment of a family of simulations on a single architecture represents a single point solution. Having attained such standardisation, history points to the likelihood that the diverse group of simulation users will quickly diverge into specialisations, leading to the need for gateways to bridge their differences. Fifth, the selection or creation of a single architecture assumes that the rapid advances of the commercial software industry will not lead to a better implementation (ie a new "better" architecture) in the future, perhaps based on a Service-Oriented Architecture (SOA) paradigm. When this does occur, the existing standard architecture would be abandoned by users who have needs for the superior architecture delivered by the commercial sources.

The simultaneous existence of multiple architectures may allow benefits that are less likely to be achieved in a single architecture state. These include: 1) the ability to support multiple business and standards-use communities simultaneously and; 2) fostering the capability to "use the right tool for the job", avoiding the "one size fits all" problem. Some specific examples include:

- DIS (Distributed Interactive Simulation): This protocol has a comparatively low barrier to entry; it is relatively simple to learn and easy to use. Also, it imposes a very low overhead. Whenever simulation events do not require using more advanced architectural services (such as time management, region-based information filtering, and so on), DIS offers a very economical solution to the system intercommunication problem;

- HLA (High Level Architecture): This architecture can serve a disparate collection of simulation systems, including those that require advanced architectural services and those that have modest requirements. In addition to its large US user base, its standing as an international standard has resulted in a high level of use in the coalition partner countries, facilitating combined simulation events that include multiple nations;

- TENA (Test and Training Enabling Architecture): This is a very capable architecture, offering much of the same capability as HLA, but based on more modern object-oriented technology. TENA middleware is offered to government users as Government-Off-The-Shelf (GOTS), unlike HLA that must be purchased on a per-seat basis; and

- CTIA (Common Training and Instrumentation Architecture): This architecture uses the service-oriented paradigm and is unique in that respect. Also, it has been designed to continue providing some level of service even in the face of unreliable communication networks. It also provides advanced service capabilities and an "on-the-wire" specification (instead of an API-level standard), thus offering potentially improved support for multiple hardware platforms, operating systems, and software development languages.

In short, the existence of multiple architectures is not necessarily an undesirable outcome and, given some of the unique benefits, could be a desirable outcome if the architectures can be easily integrated.

In summary, there are advantages and disadvantages associated with the number of architectures that are available for use. There is no paramount advantage or disadvantage that allows one to immediately recognise the best possible solution. A significant problem for the LVCAR effort is to navigate this trade space to arrive at an achievable solution that maximises the benefit for all concerned while not exceeding the resources that will be necessary to realise that solution.

4.3 Fundamental Precepts

As the LVCAR Study proceeded, a core set of beliefs, axiomatic "meta-recommendations" (ie fundamental precepts) that provided guiding principles for the implementation and execution of the roadmap, were developed. These fundamental precepts can be considered as lessons learned from the survey carried out as part of the initial work done for the LVCAR Study [LVCAR-1].

4.3.1 Fundamental Precept #1: Do No Harm

The (US) DoD should not take any immediate action to discontinue any of the existing simulation architectures. There is a considerable degree of consensus within the LVC user community that a long-term strategy based on architecture convergence would benefit the DoD. However, it is also understood that there are many design issues that must be resolved prior to implementing such a strategy, and that the actual implementation needs to be a well-planned, deliberate, evolutionary process to avoid adversely impacting participating user communities. Because of these considerations, it would be unwise to eliminate support for any of the existing simulation architectures in the near-term. Rather, as the differences among the architectures are gradually reduced, it should be the users themselves that decide if and when it is appropriate to merge their architectures into some smaller set based on both technical and business concerns. Any attempt by the DoD to mandate a convergence solution on an unwilling user base is certain to meet strong resistance and likely to fail.

4.3.2 Fundamental Precept #2: Interoperability is Not Free

The DoD must make the necessary investments to enable implementation of the activities described in the LVC Roadmap. LVC interoperability is not free. It is not reasonable to expect that LVC interoperability goals can be met with little or no investment. Since the return on LVC investments is nearly impossible to accurately quantify in the near-term, it is understood that major new up-front investments are difficult to justify. In recognition of this fact, the Roadmap has taken a long-term approach which requires only limited investment early in its implementation, with subsequent investments dependent on demonstrable progress. Without the necessary investments, the LVC Roadmap is nothing more than a blueprint of what it is possible to accomplish, with no mechanism to realise the associated benefits.

4.3.3 Fundamental Precept #3: Start with Small Steps

The DoD should take immediate action to improve interoperability among existing simulation architectures. The vast range of technical problems currently associated with the development and execution of mixed-architecture LVC environments is well recognised. Such problems increase the technical risk associated with the use of these mixed-architecture environments, and require considerable resources to address. While architecture convergence would lessen (and even eliminate) several of these problems, it is not practical to expect any significant degree of convergence to occur for many years.

Instead, LVC users need near-term solutions that reduce both cost and technical risk until such time as architecture convergence can occur. These solutions include actions such as improved gateways/bridges, common object models, and common development/execution processes. Many of these solutions can be implemented at low cost, and provide significant near- and midterm value to the LVC community.

4.3.4 Fundamental Precept #4: Provide Central Management

The DoD must establish a centralised management structure that can perform Department-wide oversight of M&S resources and activities across developer and user organisations. A strong centralised management team is necessary to prevent further divergence and to effectively enable the architecture convergence strategy. This team needs to have considerable influence on the organisations that evolve the existing architectures, and must also have influence on funding decisions related to future LVC architecture development activities. Without centralised DoD management, existing architecture communities will continue to operate in line with their own self-interests, and the broader corporate needs of the DoD will be treated as secondary issues that are likely to continue to be ignored as concerns that are not germane to the local problems.

4.4 Common Problems in LVC Events

The survey carried out for the LVCAR study found that were many common problems encountered during the preparation for, and the conduct of, mixed architecture simulation events. While some of the low-level, technical issues that needed to be resolved were unique to particular events, there was a high degree of similarity in some of the other problems that occurred for most events. Common problems occurred in the areas of design, reconciliation, and execution & test, and some of the problems impacted in all of these areas. Collectively, they represent the areas that should be addressed by activities designed to enhance the interoperability of systems during mixed architecture events.

4.4.1 Design Problems

Design problems typically required resolution before an integration event could be conducted. The problems in this group include:

- Different communities used different systems engineering models and when representatives of these different communities had to cooperate to produce a mixed architecture event, differences in process and terminology resulted in confusion and delay. The different systems engineering processes had to be correlated so that the process of designing the event could proceed;

- Because the different architectures and protocols cannot communicate directly, some type of translation resource had to be identified or created. Typically, many of the same kinds of resources (gateways, bridges, etc) had to be constructed to support each exercise. These resources are usually cost-constrained to be point solutions with little effort expended to improve their potential for reuse;

- Systems that have been built to rely on and use one architecture would not work using another architecture without non-trivial modifications. This resulted in event designers typically constraining their search for simulation systems that might participate in the event to those that were compatible with a specific architecture, rather than incur the last-resort cost of mixing architectures. In essence, the problem here is that there is no real “plug and play” capability; and

- There is some disparity in the services provided by each of the architectures (e.g., HLA provides time-management services while DIS does not). Typically, resolving the service disparity implies that only those services common to all architectures can be used across the entire event - these must be identified and remediation strategies developed, when required.

4.4.2 Reconciliation Problems

Reconciliation problems are more concerned with reconciling differences between groups of simulation systems than with design. In some cases, they could be encountered both prior to and during the integration event itself. The specific problems categorised here include:

- Typically, larger simulation events are designed to connect groups of simulations that may have been used together in smaller events (e.g., a previously designed federation). Each of these previously connected groups of systems will have already reached agreements between the interacting systems on system responsibilities and on the types of objects and interactions that would be allowed (typically included in a Federation Object Model, or FOM, in HLA federations as an example). The same kinds of agreements must be decided for the entire set of systems that will participate in the larger event. Reconciling the previously reached agreements can be difficult because the different architectures use their own mechanisms to express and record the agreements. Essentially, the problem is that federation object models must be reconciled across the different federations that will be brought together;

- The different architectures have either different standard object models or no standard object model. Object models must be reconciled for both syntax and semantics and this is often more difficult than integrating the protocols themselves; and

- The different architectures (and different implementations of the same architecture) have made unique, individual decisions concerning the specification of data as it is transmitted among participating systems. As a result, the data encoded using the conventions of one architecture cannot be decoded using the conventions of another architecture. Thus, the data differences must be reconciled and represented in a translator utility that can be interposed between the architectures.

4.4.3 Execute and Test Problems

The execute and test problem category includes issues germane to the run-time connection between simulation systems and the testing that must be applied to ensure data is being communicated correctly. These issues include:

- Legacy systems are often included in the larger events and event designers are often very constrained in their ability to modify such systems. Thus these legacy systems usually have to rely on established communications capabilities. Even when legacy system modification is possible, it is usually far more cost-effective to devise a translator than to apply a modification;

- In almost all cases, there is no external testing environment where systems can prepare for the integration event so that almost every test has to wait until the event itself. LVCAR workshop participants who have been responsible for integrating systems into such events note that: "There is never enough integration test time with a full up and running federation"; and

- External systems (e.g., C4ISR) that will be connected to the simulation event "speak their own languages" and, much like the legacy systems, these languages can only be spoken through the use of translators.

Finally, the overarching category of problems included those that spanned all three of the design, reconciliation, and test & execution areas. These problems include:

- For the most part, there is very little incentive for the different architectures to interoperate. Further, there is no source of available guidance on how they could implement solutions in a more standardised way that would promote interoperability; and

- Automated tools are not often transferable between architectures as different data formats are involved.

4.5 Some Strategies - Architectural Options or Courses of Action (COA)

According to the US LVC Architecture Roadmap (LVCAR) [LVCAR-2] many problems exist with respect to the procedures and technologies used to develop mixed architecture live, virtual, and constructive (LVC) environments. The incompatibilities between these architectures require expending a considerable amount of resources to develop point solutions that effectively integrate them into a single, unified set of supporting simulation services. Gateway solutions to these types of issues have frequently restricted exercises to using only the limited set of capabilities that are common across all of the architectures, resulting in a "dumbing down" of the more capable architectures. Further, the lack of high-level management oversight of all existing distributed simulation architectures (as a unified resource) has resulted in a situation where continued divergence of architectural capabilities is not only possible but likely, and new (potentially redundant) architectures can emerge at any time. Clearly, such issues must be satisfactorily resolved if long term interoperability goals are to be achieved.

The LVCAR study considered five advanced distributed simulation architectures that are in common use in the US:

- Distributed Interactive Simulation (DIS)
- Aggregate Level Simulation Protocol (ALSP)
- High Level Architecture (HLA)
- Test and Training Enabling Architecture (TENA)
- Common Training and Instrumentation Architecture (CTIA)

Each of these architectures was designed to address the requirements of its defined user base.

Figure 3 shows the relative use of these architectures as surveyed by the LVCAR study.

In Australia there may be some use of the minor architectures (mainly in Commercial-Off-The-Shelf (COTS) systems) however the vast majority of distributed simulation systems would be either DIS or HLA.

LVCAR Phase I efforts analysed the core requirements of each architecture and directly compared key categories of requirements. There was a high degree of functional commonality between the architectures. However, there were also some key differences, stemming from specific needs that originally drove the development of each architecture.

At the implementation level, there were significant differences between architectures that could potentially become barriers to achieving cross architecture interoperability. The study found that none of these differences introduces irreconcilable incompatibilities that prevent the integration of the different architectures into mixed architecture events. However, achieving such integration would not be without cost, and some degree of analysis/experimentation would be required to determine the best near-, mid-, and long-term solutions to addressing these incompatibilities.

A set of five potential strategies (Architectural Options or Courses of Action (COA)) were identified, and a corresponding set of advantages and disadvantages associated with each of these Courses of Action was developed. The five potential Courses of Action are:

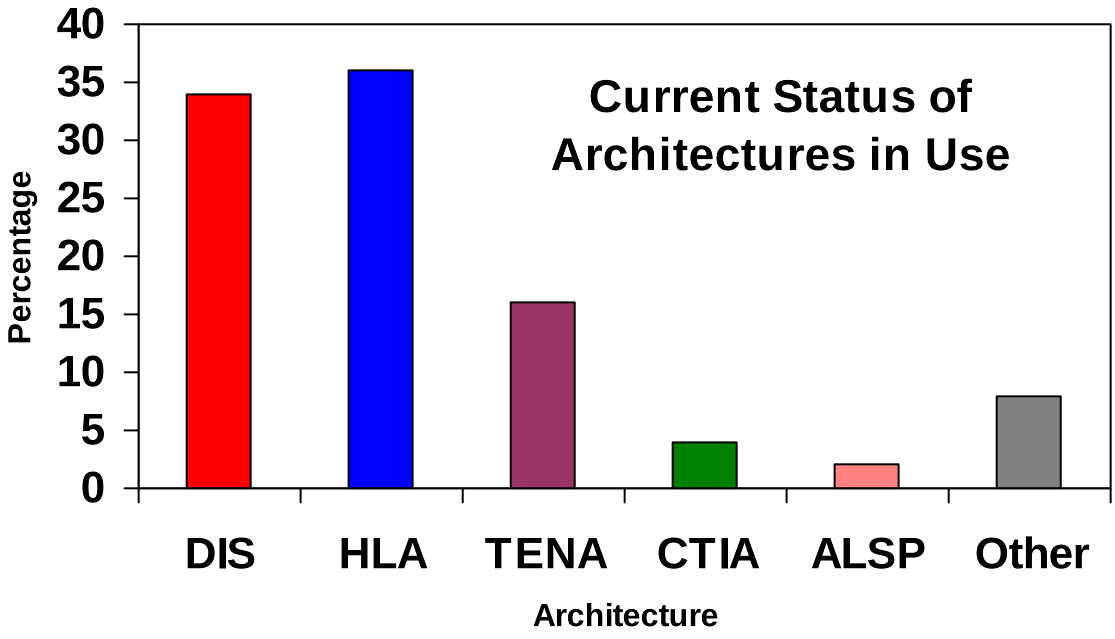

Figure 3 Typical Distribution of Architectures in Use in the US.

1. **Status Quo or "Do Nothing"** - No architectural effort to unify or enhance the existing alternatives will be undertaken. Each existing architecture will evolve based on its own users' needs, and mixed architecture events will continue to exist as currently achieved;

2. **Actively Manage the Existing Architectures** - Create standard inter-architecture integration solutions (effectively create an "architecture of architectures"). Keep the current multiple architectures but invest in improving the construction / performance / integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper". Stand up an architecture management board (both policy and technical) to oversee all of the architectures to discourage divergence and encourage compatible evolution;
3. **Convergence** – Each of the existing architectures is evolving, some quickly, some slowly. Create policy and procedures, and provide small amounts of seed money, to encourage the architectures to converge with one another in X-year time frame (e.g., 10 years). When they become so similar in features and capabilities, engineer the merging of them into a single architecture. Requires an architecture management board (both policy and technical) to oversee all of the architectures;
4. **Select One of the Existing Architectures** – Of the existing architectures, choose the one that is the most promising for the long term DoD LVC community. Use policy and funding to encourage development of the chosen architecture. Make improvements where necessary, discourage development of other architectures, and eventually get to the situation where the chosen architecture is dominant; and
5. **Develop A New Architecture** – With a better understanding of the broad DoD LVC requirements and the manifest lack of any of the current architectures to fully meet them any time in the future, create a new architecture from the best ideas of all the existing ones, and put the whole weight of the Department behind it.

4.6 Remaining LVCAR Strategies After Some Elimination

An analysis along with an assessment of how well each strategy met requirements derived from assertions that characterise the current LVC interoperability picture, led to the elimination of three strategies from further consideration. The remaining strategies (Strategies 2 and 3) are defined as follows:

4.6.1 Option 2 - Enhancing Interoperability in Mixed-Architecture Environments

Architectural Course of Action 2: Define and develop mechanisms to improve (ie enhance) LVC interoperability in mixed architecture environments, assuming that the current architectures will continue to be used.

In this COA the focus is to create solutions to improve the interoperation of existing architectures in a mixed architecture environment. Examples of such solutions include establishing standard agreements (e.g., processes, terminology, object models) that cut across the various architectures, and improving the performance, reliability and (re)usability of future gateways and bridges. The individual architectures would evolve to support their native user communities, but oversight will be provided to prevent divergence and duplication of effort. However, the oversight body is advisory not regulatory, and final control of the architecture's evolution remains with the "owning" organisation. Unlike the approaches that focus on creating an end state that includes only a single architecture, this COA assumes that there is benefit in having multiple architectures available for use, that the benefit is worth the various costs in maintaining different architectures, and that the interoperability problems inherent in mixed-architecture events can be resolved.

Primary advantages of this strategy are:

- User community requirements continue to be met based on the normal evolution of the architectures;
- Allows users to choose from a diverse set of architectural capabilities;
- Does not impose a "one size fits all" solution;
- Actively improves interoperability while providing no disruption to existing architecture users;
- Multiple architectures will spur competition between providers and likely lead to more rapid innovation;
- Benefits can be achieved incrementally; and
- Oversight Board provides a mechanism to arrest the continued development of new architectures.

Primary disadvantages of this strategy are:

- Cross-architecture integration will still be required for mixed-architecture events; and
- Funding will be necessary to support potentially overlapping architectural capability.

This strategy is founded on the idea that having multiple architectures available for use is desirable and that the best way forward is to take actions that can reduce or eliminate the barriers to interoperability (including the specific problems described above) among the existing architectures and protocols. More specifically this strategy acknowledges that the existing architectures have been created, have evolved, and are being maintained to meet the specific needs of their constituent communities. Elimination of any architecture should only occur as a natural result of disuse. Modification and management of the existing architectures are left to the owning communities as the best option to ensure meeting the needs of the various user communities, both throughout the DoD and among the Department's coalition partners. To resolve interoperability problems, efforts should be directed towards creating and providing standard resources, such as common gateways, common componentised object models, and common federation agreements, which can resolve the problems identified in the preceding section and render integration of the multiple architectures an efficient and nearly transparent process. In effect, these actions will create the perception of a single architecture that supports all the diverse simulation systems, even though the systems will actually be serviced by an "architecture of architectures", comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

4.6.2 Option 3 - Convergence

Architectural Course of Action 3: Develop policy and incentives to encourage existing architectures to converge (over some defined period of time) to either a single architecture or a smaller set of architectures; ie encourage and facilitate architecture convergence.

This COA 3 is very similar to COA 2, with the exception that a regulatory oversight body will implement policy actions and investment incentives (including disincentives) to cause the architectures to converge either into a single architecture or at least a smaller set of compatible and interoperable architectures. Thus, while the same roadmap actions could be taken with regard to improving both model and runtime interoperability in the near- to mid-term, this COA will include additional actions as necessary to achieve an appropriate level of architecture convergence (including potential physical convergence) at a specified future date.

Primary advantages of this strategy are:

- Multiple architectures will compete to be the "convergence target", fostering competition between providers and likely leading to more rapid innovation;
- Needed architectural changes are phased-in to avoid user community disruptions;
- Benefits can be achieved incrementally; and
- Eliminates much of the complexity of mixed architecture environments in the long-term if physical convergence can be achieved.

Primary disadvantages of this strategy are:

- Disruption to users, in that the final actions to achieve convergence may be unacceptable to existing architecture users;
- Requires that hard choices be made regarding several technical and business model issues, which may provide disincentives for affected users to transition; and
- Uncertainty about the degree of convergence that can be achieved has potential for (ie results in) failure.

Strategy 3 (ie COA3), "Encourage and Facilitate Architecture Convergence", is clearly related to Strategy 2 (COA2), but focuses on converging services across the architectures as the primary effort. This strategy rests on the fundamental cost-avoidance concept that the current set of architectures and protocols includes significant overlapping capability and that the differences associated with the implementations of these overlapping capabilities should be reduced whenever possible.

In this strategy, the existing architectures will be converged by modifying those architectures that now provide similar services so that they actually provide the same service. Convergence could be applied as an evolutionary process that could eventually result in a smaller set of more compatible architectures. In the limit, if full convergence could be achieved, all of the existing architectures would become so similar that they would effectively become a single architecture.

Altering the ways in which fundamental architectural services are provided to achieve a common implementation across several architectures is a technically demanding undertaking. The difficulty of this task should not be underestimated and a significant amount of up-front analysis and design needs to occur prior to applying modifications to any of the architectures. Modifications should only be applied when they do not change the fundamental nature of the architecture itself and when the modifications can be made in a way consistent with the other services provided by that architecture.

However, the process of convergence will necessarily take place over an extended period of time. Because the LVC interoperability problem is immediate, Strategy 3 also includes the near-term actions that form the basis of Strategy 2. That is, the same set of actions required to reduce or eliminate the architecture-integration effort for mixed-architecture events are also required in Strategy 3 to enable convergence.

4.7 The Way Ahead

Summing up, Option 2 is based on the assumption that the current state of multiple, somewhat overlapping, architectural capabilities is useful and seeks to take actions that will make integrating these existing architectures easier, without forcing modifications of the architectures themselves. Option 3 recognises the immediate need for creating the same set of resources to achieve interoperability, but characterises those resources as interim measures that should eventually become less necessary as the existing architectures converge into a smaller, more compatible and easily integrated set. Thus, the near term requirements for enhancing the current interoperability picture look very similar, regardless of the ultimate strategy.

The near- to mid-term activities that could occur as parts of either strategy cover a wide range. Some are useful only within the context of attempting to achieve architectural convergence. Others involve resources that will reduce the effort required to achieve integration required as part of creating mixed architecture simulation events. Others are useful in either undertaking. These actions and activities include feasibility studies, planning efforts, implementation efforts, and capabilities analyses. Ultimately, the selected set of activities will constitute the recommended course of action in the LVCAR Roadmap. The interoperability enhancing activities that have been identified include:

- Devise the common components of architecture-independent object models;
- Produce common gateways and bridges;
- Create a common, reusable federation agreement template;
- Provide an analysis of the processes and infrastructure supporting M&S asset reuse;
- Describe and document a common, architecture-independent systems engineering process;
- Produce and / or enable reusable development tools;
- Implement a process to maintain specifications for current and future requirements;
- Specify a resource to facilitate pre-integration systems readiness; and
- Determine the feasibility of a common wire-level protocol.

The following sections describe each of these potential activities in more detail. Relationships (potential dependencies) between them are also presented. These relationships are used to create a sequence of actions that could be viewed as an initial roadmap of activities that will improve the current state of LVC interoperability.

4.7.1 Common Components of Architecture-Independent Object Models

Reconciling the differences between the various formats and content of the object models used in different M&S user communities has been recognised as a source of excessive resource consumption when building mixed architecture environments. Providing a common object model, comprised of common components (object model building blocks, sometimes referred to as base object models) and including mappings to current architecture object models, would allow mixed architecture integration to proceed faster and easier.

4.7.2 Produce Common Gateways and Bridges

According to the LVCAR study gateways are the most widely used method to link disparate simulations together. Gateways have demonstrated an impressive range of capabilities across the simulation communities that employ them, such as the ability to translate between different protocols or object model representations and to address disparities in the services typically encountered in mixed architecture environments (e.g., time management, filtering, etc.). However, most gateways are designed as point solutions for specific problems, and are rarely shared across user organisations. Thus, the same basic capabilities tend to get developed multiple times, and programs may not even know about more advanced features developed by other organisations.

The adoption of common object models would reduce the complexity and individuality of gateways required, eventually leading to a standard set of gateways and bridges along with supporting user and developer documentation. Possible "missing services" could be incorporated within the gateways and such common inter-architecture translator gateways would become readily available assets thereby relieving individual programs and organisations of the need to develop their own gateways with specific capabilities.

4.7.3 Create a Common, Reusable Federation Agreement Template

According to the LVCAR study many of the issues that arise when developing distributed simulation environments require the establishment of agreements among all federation participants as a precursor to resolution. Currently, there is no architecture independent standard format or content for Federation Agreements documents. Thus, programs must continuously rediscover what types of information require cross-federation agreements, and the lack of a standard format adversely affects the reusability of these products.

The purpose of this task is to develop an architecture-independent template for establishing Federation Agreements, along with potential architecture-specific extensions. This activity is primarily designed to address problems that arise due to differences between Federation Object Models (FOM). While the activity is not designed to produce a standard FOM, it should produce a standardised template that would permit the FOM reconciliation task to proceed much more easily. The product of this effort will be an architecture-independent template for establishing Federation Agreements, along with potential architecture-specific extensions.

4.7.4 Describe and Document a Common, Architecture-Independent Systems Engineering Process

When the user communities of different architectures are brought together to develop a single mixed architecture distributed simulation environment, the differences in the development processes native to each user community represent a persistent barrier to effective collaboration. That is, since these communities must work together toward a common goal, differences in the practices and procedures these communities typically use to build new simulation environments can lead to misunderstandings, misinterpretations, and general confusion. This introduces risk from both the technical and schedule perspectives.

A common systems engineering process model needs to be developed for all users of distributed simulation. Existing architecture-specific process models (DIS - IEEE 1278.3 – Exercise Management and Feedback - Recommended Practice, HLA - IEEE 1516.3 Federation Development and Execution Process (FEDEP) - Recommended Practice, TENA ConOps, etc) will be examined to identify the key similarities and differences, and a consensus-building process will be instantiated to develop the required product. The product from this activity will be a common systems engineering process model that can be applied across the full range of DoD distributed simulation users. Specific implementation guidance that describes how the common process model should be tailored to meet the needs of specific architecture users will also be included as part of this activity. Finally, an Architecture User Guide will be included as an annex to the core document. This guide would define a mapping between the type of simulation event and the architecture or protocol that offers best support for that purpose.

4.7.5 Common Tools

Some examples of common tools that could be used by any or all participating LVC systems include requirements development tools, scenario development tools, conceptual and object modelling tools, design tools, networking tools, testing tools, After Action Review (AAR) tools, etc. Many such tools would already be in use in DSTO and each tool would have a corresponding business model such as COTS, GOTS, and proprietary (DSTO developed) solutions. The various business model options associated with each tool may be a significant impediment to sharing these tools across the ADF.

Another potential barrier to reuse of tools is that there are many different formats used by the different architectures to store exercise data. Different data storage formats used across the various architectures should be examined to determine the feasibility of using a set of architecture-independent formats for storage of classes of data.

A library of cross-community reusable tools for LVC environment development, along with a business model for tool distribution should be created and a set of architecture-independent data storage formats, specified according to type of data and allowing the tools to operate in different architecture environments, should be investigated.

4.7.6 Specify a Capability to Facilitate Pre-integration Systems Readiness

Simulation system integration into large simulation events can be a very lengthy process of error detection and remediation. This problem could be reduced if individual or small numbers of simulation systems could be more fully tested for integration readiness prior to integration into the actual exercise event.

A test integration capability should be developed including such capabilities as establishing reusable simulation exercises that include multiple systems using all of the architectures that are currently used in DoD events. Such a resource should be developed to allow join and resign actions by individual simulation systems over existing networks. The joining systems (e.g., the systems under test) would be required to originate and receive interactions to and from simulation systems residing on a variety of architectures. Such a capability would reduce the time required to complete the integration cycle, thus addressing a problem in the execute and test problem group.

This approach is the basis of the standards-based methodology used by the USAF DMO program whereby a LVC system cannot connect and interoperate on the DMO Network (ie join and participate in a DMO exercise) unless it has been tested and found to be compliant with USAF DMO interoperability standards [Aldinger], [Zalcman (2010)]

4.7.7 Determine the Feasibility of a Common Wire-Level Protocol and a Common API

For those architectures that include an API standard, the wire protocol for intercommunication with other simulations is embodied in the middleware, and thus is completely opaque to most users. However, if the wire protocols used by different middleware applications are different, it is impossible for the middleware applications to interoperate at runtime unless appropriate bridges or gateways are put into place. This is the case for HLA [Tudor]. These translation utilities represent a potential source of error, consume valuable program resources to develop and integrate, and add complexity to the architecture of the M&S environment.

Whether a "common API" is feasible should also be determined. That is, there could be a higher-level API, with its own specification of function calls that could ultimately be translated into the calls defined in either the TENA or HLA API. Use of such an API, in a simulation application, would permit compilation to either of the target architectures (HLA or TENA).

The COTS MaK Technologies VR-Link toolkit adopts this approach in that a common, higher-level API provides support for DIS, HLA 1.3, HLA 1516, and TENA [MaK]. Presumably VR-Link will be upgraded to provide support for HLA Evolved also.

This common API approach should also be considered for DSTO (AOD and Net Warrior) support of the Link-16 tactical data link protocol. In DSTO's Air Operations Division the Airborne Systems Connectivity Environment Laboratory (ASCEL) supports Link-16 interoperability using the Rockwell Collins Rosetta toolkit [Filippidis]; the DSTO developed ADGESIM system supports Link-16 interoperability using the TCG Link-PRO toolkit [Zalcman (2009)-1], [Zalcman (2009)-2]; and the Air Operations Simulation Centre is developing its own proprietary toolkit to support Link-16 interoperability. A common API system should be developed to provide higher-level support for all these Link-16 toolkits.

The LVCAR Study recommends that the feasibility of developing a common wire protocol across different architectures and a common (higher-level) API should be investigated. In the case of HLA, it would also involve determining the feasibility of a common wire protocol and

API for different versions of the RTI (e.g., RTI-S, HLA 1.3 RTIs and HLA 1516 RTIs (HLA-Evolved?)). The activity would include an examination of the different wire protocols and APIs in use today, and identifying and resolving the various technical, business, and standards issues involved with achieving the necessary consensus agreements across the various architecture developers. Note that, in addition to feasibility, this effort should also address some of the desirability aspects of the problem. That is, it may be that both a common wire protocol and API are technically feasible and could be implemented from both a business and standards sense, but it still may not be desirable to pursue either one, either for cultural reasons or for reasons related to the potential impact on commercial developers.

If possible a common wire-level protocol would facilitate the development of common, reusable tools and utilities, and the development of a pre-integration readiness capability. The availability of either a common wire protocol or a common API would simplify the problem of creating common gateways and bridges.

4.7.8 Enabling Interoperability Now and Architecture Convergence in the Future

The activities described in this current section will improve interoperability in mixed architecture events as soon as the associated resources can be made available. Some of these activities lead directly to converged architectural capabilities, primarily regarding HLA, TENA, and CTIA. According to the LVCAR study:

> *"It is much less desirable to seek a high degree of convergence for DIS because adding the necessary services to that protocol would effectively undermine the advantage it now enjoys; it currently provides the essential intercommunication services without adding excessive user burdens or complexity."*

4.7.9 Model Consistency

Incompatibilities in the way real operations are represented in different simulations can significantly affect the validity of simulation interactions. "Fair fight" issues can sometimes occur simply due to the underlying algorithms the various simulations use to model real world phenomena. For instance, if two simulations within a distributed simulation environment are representing the exact same radar (with exactly the same system data) but use different algorithms for modelling detection and tracking performance, it is quite possible for different instantiations of the same radar to perform differently. Obviously, such artificialities would not occur in the real world, and thus the validity of the simulation results would be compromised.

The need in this area is to examine the algorithms currently used to model real world systems and phenomena of military interest, and determine if agreements can be achieved across user communities on standards for common algorithms. The scope should be based on an assessment of which algorithms are most common across DoD simulations and where agreements across user communities are most feasible.

In addition to standardisation of algorithms, it is desired that implementations of those standards be made available for general reuse in the M&S community. Therefore there is also a need to address the use of repositories for reusable M&S software distribution, as well as the business and cultural issues and associated incentives required to facilitate widespread sharing of models across programs and whole communities.

4.7.10 Environmental Representations

There has been a considerable amount of work across the Services and various DoD agencies to reduce the amount of effort required to develop and share environmental data for use within DoD simulation events. Examples include the SEDRIS standard for environmental data interchange and the Environment Scenario Generator (ESG) for production of environmental databases. However, ensuring that use of different simulated environments can result in valid system-to-system interactions remains a persistent problem in distributed simulation events. The notion of "correlating environment representations" permeates the community, without a common understanding of the processes necessary to achieve fully interoperable simulated environments. Thus, there are needs to craft a procedural definition of environmental correlation, identify the main barriers to implementing a complete, consistent environmental representation management strategy, and identify effective implementation policies. Missing resources include a technical strategy and implementation approach for improving the representation of the environment in LVC environments. The implementation approach should address tool requirements and business model considerations.

4.7.11 Human Behavior Modelling

The sheer size of modern battlespaces dictates the need for Constructive (such as Semi-Automated Forces (SAFs), Computer Generated Forces (CGFs), etc) applications to simulate human behaviors. That is, there are so many human participants in simulations of current and predicted military engagements that having live operators for all decision-making entities is just not possible. Many live training events use SAF for opposing forces, but many also use SAF for friendly forces they must cooperate with to achieve identified objectives. While considerable research has gone into this area the requirement for realistic and consistent SAF representations across the full range of entities that play in modern warfare representations is still largely unmet.

The need in this area is to examine the current state of human behavior modeling within the DoD, identify gaps, and develop potential solutions that not only meet gaps in functionality, but also address functional inconsistencies that can occur in mixed architecture environments. The strategy here should emphasise the standardisation and sharing of existing capabilities (e.g., JSAF, OneSAF) rather than performing new research. Mechanisms to extract such capabilities from specific M&S systems so that they can be reused in other M&S systems must be emphasised whenever feasible.

4.7.12 Bridging Multiple Security Domains

Issues of security are extremely important when conducting a distributed LVC simulation event. When the entire event is conducted at a single level of security, the mechanisms to ensure that security policies and procedures are being fully addressed are generally well understood. However, many distributed events involve the integration of "enclaves" of LVC systems that operate at different levels of classification. Current mechanisms to bridge across different security levels are very expensive and time consuming to implement, and verifying that the guards are operating correctly (as part of overall LVC environment testing) is often unacceptably resource intensive.

The need in this area is to examine the issues related to bridging multiple security domains, based on user requirements. Policies, methodologies, and technologies must all be considered in deriving an optimal overall solution for future users of LVC environments.

4.8 LVCAR Study Conclusions and Recommendations

4.8.1 Technical Area Conclusions

Each of the existing architectures provides useful service to a dedicated user community. While there are many similarities between these architectures, there are also differences (largely apart from technical capabilities, but including important cultural and business model factors) so that each architecture has an appropriate role within the entire community. The similarities among the architectures are based on technical service capabilities and these similarities could be exploited and increased to lessen the problems encountered during mixed-architecture integration efforts. One way to enhance the similarities among the architectures is through a process of managed capability convergence, intentionally modifying selected services, by architecture, to create commonality. DIS only presents limited opportunities for convergence (section 4.7.8). Higher levels of convergence are feasible for HLA, TENA, and CTIA. Apart from convergence, there are also opportunities to improve mixed architecture interoperability by creating commonly used resources (external to any of the architectures) such as gateways, common object model components, and other resources already described above. In short, where the architectural resources available to the Department (US DoD) are providing a high level of service, full replacement is not necessary. The priority need is to make the available architectures capable of easily working together and this can be done by exploiting opportunities to converge services and by providing interoperability-enhancing resources.

There is also a need to stop the further creation of alternate architectures. There is no evidence that current or future requirements cannot be met by the available resources, either as they stand today or after some level of enhancement. Further, enhancing one or more of the available architectures to meet unresolved needs is preferable to creating “new and improved” alternate architectures, not only from a cost basis, but from an interoperability perspective as well. One lesson of history is that, if a new architecture is created to replace one or more of the existing set, the most likely outcome is that there will simply be one more architecture added to the available set. Also retiring an architecture has proven very difficult.

4.8.2 Technical Area Recommendations

1. All of the existing architectures should continue to receive support in the immediate future. Subsequent to the conclusion of the convergence service area feasibility experiments, one or more of the architectures may be subsumed by a converged capability, providing a rational basis for ending US DoD support to the subsumed architecture (s).

2. DIS should only be considered as a candidate for limited convergence. This protocol provides unique services and capabilities that would be lost were the protocol to be fully converged with other architectures that serve different communities and necessarily provide higher levels of service capability. While some of the activities that could lead to more service-level compatibility (e.g., common, components of object models, standard wire-level protocols, etc.) between DIS and the other architectures will prove advantageous, DIS should remain much as it is today, a lightweight, core capability protocol.
3. From a technical point of view, there are significant opportunities to converge the services provided by HLA, TENA, and CTIA. A follow-on effort to conduct additional, more detailed analyses and experiments should be chartered. This effort should be focused on producing qualitative data that can lead to informed decisions on specific service capabilities to be converged. Whether or not such service-level convergence leads to eventual architecture convergence, achieving a state where these architectures provide very similar services will facilitate interoperability and decrease the integration effort when conducting mixed-architecture events.
4. The creation of a common, component-based object model should be aggressively pursued. The Department should leverage existing efforts in this area now underway at JFCOM and ensure that the result spans joint needs across the entire Department.
5. The creation of shared and reusable intercommunication mechanisms (e.g., gateways and bridges) should be aggressively pursued. A follow-on effort to produce the technology required in this area, to include specification of suitable discovery and distribution mechanisms should begin as soon as supporting resources can be made available.

4.9 Section Summary

The Live-Virtual-Constructive Architecture Roadmap (LVCAR) is intended to guide actions and decision-making on the development, employment and integration of US DoD LVC environments and architectures over the next 10 years.

The purpose of the LVCAR Study (phase 1 of the LVCAR) was to develop a future vision and supporting strategy to achieve significant interoperability improvements in LVC simulation environments.

To support the implementation of this strategy the LVCAR study specifies near-, mid-, and long-term actions that collectively delineate a roadmap that begins to guide the evolution from the current state of LVC environment development to achieve the desired future vision. However in such a complex environment, mid-course adjustments would be expected.

The presence of multiple protocols/architectures and the (incorrect) perception that interoperability would be much easier (and less costly) if only a single architecture were available has been discussed.

The LVCAR Study developed four core principles (fundamental precepts) which were:

- **Do No Harm** - The (US) DoD should not take any immediate action to discontinue any of the existing simulation architectures. Rather, as the differences among the architectures are gradually reduced, the users themselves should decide if and when it is appropriate to merge their architectures into some smaller set based on both technical and business concerns. Any attempt by the DoD to mandate a convergence solution on an unwilling user base is certain to meet strong resistance and would be likely to fail.

- **LVC Interoperability is not free** - The DoD must invest resources to enable the activities described in the LVC Roadmap. However the Roadmap recommends a long-term approach which requires only limited investment early in its implementation, with subsequent investments dependent on demonstrable progress. Without the necessary investments, the LVC Roadmap is nothing more than a blueprint of what it is possible to accomplish, with no mechanism to realise the associated benefits.

- **Start with Small Steps** - The DoD should take immediate action to improve interoperability among simulation architectures. LVC users need near-term solutions (improved gateways/ bridges, common object models, and common development/execution processes) that reduce both cost and technical risk until architecture convergence (many years) can occur. These solutions may be low cost, and provide significant near- and mid-term value to the LVC community.

- **Provide Central Management** - The DoD must establish a centralised management structure that can perform wide oversight of M&S resources and activities across developer and user organisations to prevent divergence and enable the architecture convergence strategy. This team needs to have considerable influence on funding decisions related to future LVC architecture development activities. Otherwise existing architecture communities will continue to treat DoD requirements as secondary issues that are likely to be ignored as concerns that are not germane to the local problems.

A set of five potential strategies were identified and investigated:

- **Status Quo or "Do Nothing"**;
- **Actively Manage the Existing Architectures**;
- **Convergence**;
- **Select One of the Existing Architectures**; and
- **Develop A New Architecture**.

Two strategies (Courses of Action (COA)) were recommended:

- **Actively Manage the Existing Architectures** - Create standard inter-architecture integration solutions. Keep the current multiple architectures but invest in improving the construction / performance / integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper"; and

- **Convergence** - Create policy and procedures, and provide small amounts of seed money, to encourage the architectures to converge with one another in the long term time frame (e.g., 10 years). When they become so similar in features and capabilities, engineer the merging of them into a single architecture.

The interoperability-enhancing set of activities that will result in a recommended course of action were identified and include:

- Devise the common components of architecture-independent object models;
- Produce common gateways and bridges;
- Create a common, reusable federation agreement template;
- Describe and document a common, architecture-independent systems engineering process;
- Develop and / or use reusable common tools;
- Implement a process to maintain specifications for current and future requirements; and
- Facilitate pre-integration systems readiness.

5. How is the US DOD LVCAR Study Relevant to the ADF?

The LVCAR Study was carried out by the US DoD and is applicable to the US LVC environment. The Net Warrior initiative is DSTO only; however it should be indicative of the LVC environment in the ADF.

Comparing the situation found in Net Warrior in DSTO with what was found in the LVCAR Study in the US may give valuable insights into the ADF LVC environment in Australia - that is, are the LVCAR Study strategies, precepts, assumptions, etc. useful and relevant to the ADF?

5.1 The DSTO (AOD) Net Warrior Initiative

The DSTO Net Warrior initiative was conceived to address, through experimentation, new and evolving network centric capabilities and mission system technologies to enhance ADF joint war fighting capabilities [Foster], [Sioutis]. With this as the prime objective, Net Warrior will be in part the realisation of a general ambition in DSTO to create a research network of (NCW enabled) Battlelabs [Filippidis].

Initially, the Net Warrior initiative developed a persistent network infrastructure to support a research capability in NCW by connecting a set of nodes which are test-beds representing current or potential future ADF assets [Lawrie], [Zalcman (2006)], [Zalcman (2007)], [Zalcman (2008)]. The nodes were selected using the criteria of:

- The need for interoperability of the real assets;

- The significance of the real assets in joint operations;
- Whether high fidelity representations of the assets exist or are planned in DSTO; and
- Whether experimental representations of potential assets would benefit from participating.

The DSTO nodes will be high fidelity representations of airborne and maritime assets and will include AEW&C (Airborne Early Warning & Control), an Air Defence Ground System (ADGE) and a future ship. Higher fidelity test-beds will allow evaluation of real systems and investigation of technical issues.

These nodes already exist in some form, but at present are not able to interoperate appropriately. The test-beds will evolve in themselves as integral components of the Net Warrior network and as stand-alone components of research capabilities with platform centric research objectives. Where there is common interest, exercises will be run that involve all nodes or a subset of these nodes.

An objective of Net Warrior is to support coalition (eg DMO) interoperability however there currently are no existing Net Warrior interoperability standards (ie a Net Warrior Synthetic Range Interoperability Model).

The development of such a set of coalition compliant, Net Warrior interoperability standards will accelerate the development of coalition compliant interoperability for individual Net Warrior systems since it is assumed that the (Net Warrior) Synthetic Range Interoperability Model used will define a set of (distributed simulation, radio communications and tactical data link) interoperability standards that should be very similar to the interoperability standards used by coalition partners such as the USAF DMO Program. Therefore ADF LVC systems (eg Net Warrior LVC systems) that are compliant with the recommended ADF Corporate Synthetic Range Interoperability Model should then also be highly interoperable with coalition LVC systems such as USAF DMO compliant, LVC systems.

5.2 What Advanced Distributed Simulation Protocols Need To Be Supported?

Figure 3 shows that the US has to deal with at least five Advanced Distributed Simulation protocols/ architectures (HLA, DIS, TENA, ALSP, CTIA etc.) where DIS and HLA each account for approximately 35% of the systems surveyed in the LVCAR Study.

In Australia most simulation systems with external interoperability will be either DIS or HLA. This is extremely convenient as any discussion as far as the ADF is concerned can be limited (has already converged) to just DIS and HLA.

Only having to deal with DIS and HLA will enable the ADF to more easily comply with both:

- Strategy (COA) 2 - Enhancing Interoperability in Mixed-Architecture Environments: Define and develop mechanisms to improve (ie enhance) LVC interoperability in mixed architecture environments, assuming that the current architectures will continue to be used; and

- Strategy (COA) 3 - Convergence: Develop policy and incentives to encourage existing architectures to converge (over some defined period of time) to either a single architecture or a smaller set of architectures.

According to the LVCAR Study the desired state is one where there is only a single architecture, either due to convergence, or the creation of reusable intercommunication resources that will make different architecture implementations appear as a single resource, or a combination of these two developments.

However, also according to the LVCAR study it is much less desirable to seek a high degree of convergence for DIS because adding the necessary services to that protocol would effectively undermine the advantage it now enjoys where it currently provides the essential intercommunication services without adding excessive user burdens or complexity.

Therefore for the ADF:

- DIS and HLA account for most of the simulation systems used in the ADF;
- DIS and HLA are unlikely to be able to be converged to a single architecture; and therefore
- Both DIS and HLA will have to be supported.

5.3 Net Warrior Fundamental Precepts

The DSTO Net Warrior initiative [Foster], [Sioutis] will reflect the situation found throughout the ADF in that Net Warrior experiments will require that interoperability be established between various DSTO Net Warrior nodes (representing ADF nodes) depending on the objectives of the research or experimentation undertaken.

Sections 5.3.1 to 5.3.4 replicate the LVCAR Fundamental Precepts (sections 4.3.1 to 4.3.4) from the Net Warrior point of view.

5.3.1 Net Warrior Fundamental Precept #1: Do No Harm.

According to the LVCAR Study "it would be unwise to eliminate support for any of the existing simulation architectures in the near-term. Rather, as the differences between the architectures are gradually reduced, it should be the users themselves who decide if and when it is appropriate to merge their architectures into some smaller set based on both technical and business concerns. **Any attempt by the ADF/DSTO/Net Warrior to mandate a convergence solution (ie a single architecture) on an unwilling user base is certain to meet strong resistance and likely to fail**."

Imagine telling DSTO's Maritime Operations Division that they had to (ie were mandated to) convert the HLA Virtual Ship Project to support DIS !!! Not only would this be likely to be ignored but in fact it would most likely be extremely difficult to get the MOD Virtual Ship simulation system to interoperate using DIS – this would take a (very) long time to implement.

Imagine Net Warrior telling the AOD AOSC DACS (Deployable Aircraft Cockpit Simulator) development team that they must use HLA - again this would simply be ignored as there is simply no requirement for the AOSC DACS systems to use HLA as the AOSC has standardised on DIS and therefore the DACS interoperates using DIS. Similarly ADGESIM (see Figure 4) has standardised on DIS.

The recommended Net Warrior (and the corporate ADF) LVC Synthetic Range Interoperability Model should support both DIS and HLA interoperability.

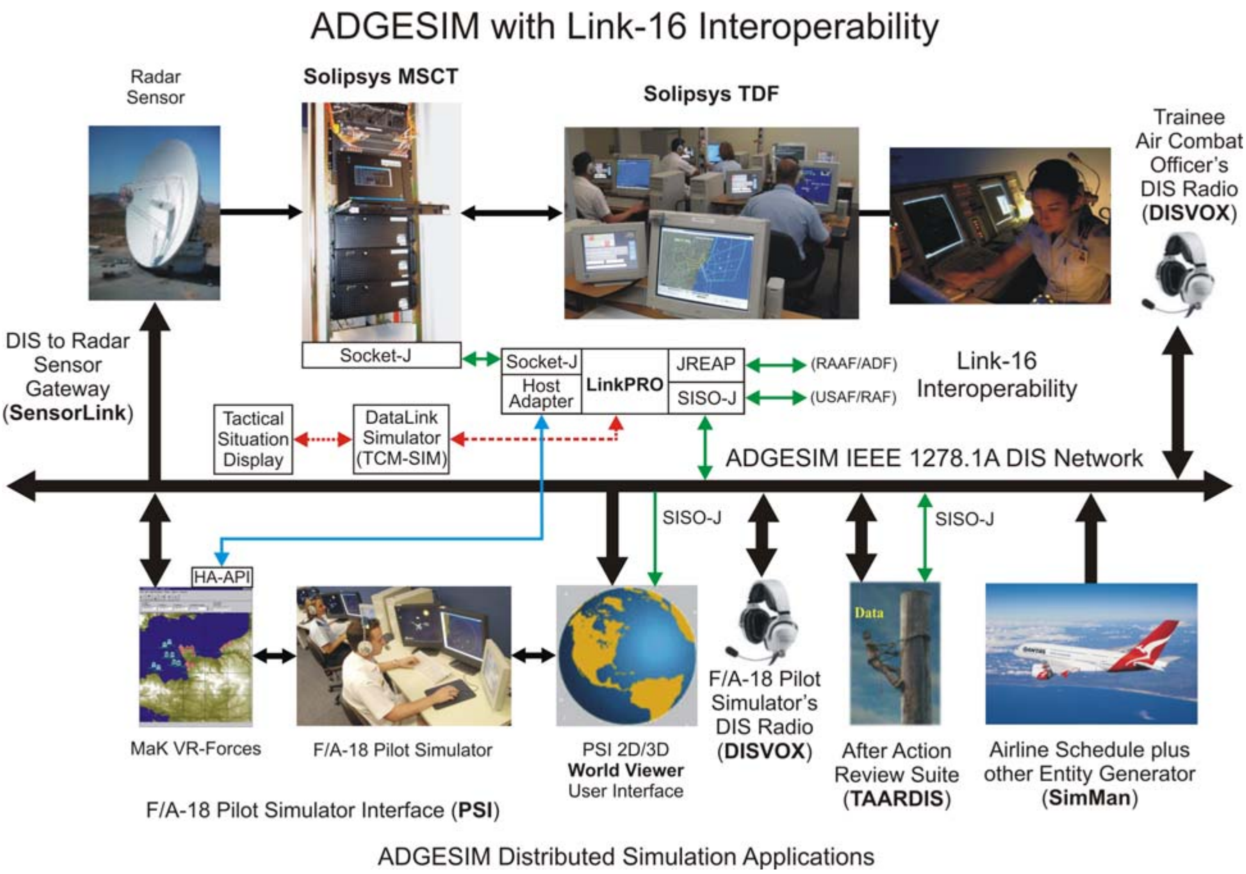

Figure 4 The ADF Corporate Synthetic Range Interoperability Model Compliant ADGESIM

5.3.2 Net Warrior Fundamental Precept #2: Interoperability Is Not Free.

The necessary investments must be made to implement LVC interoperability - it is not free. It is not reasonable to expect that LVC interoperability can be achieved with little or no investment.

Currently each simulation system itself is responsible for funding interoperability with other simulation systems. There is no centrally managed DSTO or AOD task responsible for (Synthetic Range) Net Warrior interoperability for the various divisional Net Warrior nodes. Therefore Net Warrior node interoperability has no priority or specific funding and is actually resourced as part of individual DSTO divisional tasks.

There are no Net Warrior, DSTO, or ADF corporate interoperability standards!

Net Warrior interoperability standards need to be tasked, resourced and developed to initially reduce risk; and then move from reducing risk, towards "*Guaranteeing Interoperability*" which is far more difficult to achieve!

5.3.3 Net Warrior Fundamental Precept #3: Start With Small Steps.

DSTO/AOD should take immediate action to improve interoperability among existing Net Warrior simulation system architectures. The vast range of technical problems currently associated with the development and execution of mixed-architecture LVC environments is well recognised. Such problems increase the technical risk associated with these mixed-architecture environments, and require considerable resources to address. While architecture convergence would lessen (and even possibly eliminate) several of these problems, it is not practical to expect any significant degree of convergence to occur for many years.

The longer you leave it (ie do not address this problem) the worse it will get!

The current work towards developing a Net Warrior Interoperability Migration Strategy eventually resulting in Net Warrior Interoperability Standards is an essential (and initially a) small step in the right direction!

5.3.4 Net Warrior Fundamental Precept #4: Provide Central Management.

A set of Net Warrior Interoperability standards should be developed or specified to prevent further divergence and to effectively enable the architecture convergence strategy. Without any interoperability standards (and funding to support development of individual DSTO divisional Net Warrior node interoperability) existing architecture communities will continue to operate in line with their own self-interests, and the broader corporate needs of DSTO and Net Warrior will be treated as secondary issues that are likely to continue to be ignored as concerns that are not relevant to the local problems.

As per 5.3.3 - **the current work towards developing a Net Warrior Interoperability Migration Strategy eventually resulting in a Net Warrior Strategy (ie this report) and Net Warrior Interoperability Standards is an essential (and initially a) small step in the right direction! However it cannot be allowed to occur in an ad-hoc fashion - it must be (ie centrally) managed, tasked and resourced.**

5.4 Section Summary

The Net Warrior initiative is DSTO only however it should be indicative of the LVC environment in the ADF.

In the US there are at least 5 different Advanced Distributed Simulation protocols/architectures in use – DIS, HLA, TENA, ALSP and CTIA. In Australia almost all LVC systems will be DIS or HLA.

According to the LVCAR Study - DIS should only be considered as a candidate for limited convergence. DIS should remain much as it is today, a lightweight, core capability protocol.

Therefore for the ADF:

- DIS and HLA account for almost all of the LVC systems used in the ADF;

- DIS and HLA are unlikely to be able to be converged to a single architecture; and therefore
- Both DIS and HLA will have to be supported.

Some lessons learned from the US DoD LVCAR Study and the DSTO Net Warrior initiative that should be applicable to the ADF are:

- **Do No Harm** - Any attempt to mandate a convergence solution (ie a single architecture) on an unwilling user base is certain to meet strong resistance and is likely to fail;
- **Start With Small Steps** - The current work towards developing a Net Warrior Interoperability Migration Strategy (ie such as this report) eventually resulting in Net Warrior Interoperability Standards is an essential (and initially a) small step in the right direction;
- **Interoperability is Not Free** - There are no Net Warrior, DSTO, or ADF corporate interoperability standards such as those being discussed in this report! Net Warrior interoperability standards need to be tasked, resourced and developed to initially reduce risk; but then move from reducing risk towards "*Guaranteeing Interoperability*" which is far more difficult to achieve; and
- **Provide Central Management** – Unless centrally managed, existing ADF / DSTO / Net Warrior LVC communities will continue to operate in line with their own self-interests, and the broader corporate needs of the ADF / DSTO / Net Warrior will be treated as secondary issues that are likely to continue to be ignored as concerns that are not relevant to local problems.

6. What Interoperability Models are Others Using?

6.1 Comparison of Synthetic Range Interoperability Models

Table 2 provides an analysis of various coalition LVC systems in order to compare their LVC Synthetic Range Interoperability Models and the interoperability standards used [Zalcman (2010)].

The recommended ADF Corporate Synthetic Range Interoperability Model (Table 3) defines the minimum level of interoperability that all potential ADF LVC interoperable systems should be specified (ie mandated) to have when acquired by the Commonwealth [Zalcman (2010)].

The ADF Corporate Synthetic Range Interoperability Model shown in Table 3 is only defining the required data at (ie down to) the PDU level (ie common object models). The objective of developing the ADF Corporate Synthetic Range Interoperability Model is that it would eventually define interoperability standard components (DIS PDUs (Table 3), DIS PDU fields, enumerations, etc.) precisely and unambiguously so that each compliant LVC system should be highly specified and highly interoperable "out-of-the-box".

Table 2 Comparison of Various Synthetic Range Interoperability Models.

Model Name	ADS	Radio Comms	Tactical Data Link
USAF (DTE5)	DIS IEEE 1278.1/A Entity State PDU Fire/Detonation PDU EE PDU IFF PDU	ASTi DACS Transmitter PDU Signal PDU Receiver PDU	Link-16 SISO-J
USN (DTE5 and Watson experiments)	DIS IEEE 1278.1/A Entity State PDU Fire/Detonation PDU EE PDU IFF PDU HLA DTE FOM MaK RTI	ASTi DACS Transmitter PDU Signal PDU Receiver PDU	Link-16 SIMPLE
US Army (DTE5)	DIS HLA DTE FOM MaK RTI MATREX FOM MATREX RTI	ASTi DACS Transmitter PDU Signal PDU Receiver PDU	None? (must now be VMF)
UK MASC	DIS HLA	DIS Voice Comms Transmitter PDU Signal PDU	Link-16 SISO-J
NATO Spanish LVC	DIS IEEE 1278.1/A HLA IEEE 1516 RPR-FOM V2D17 MaK RTI	Verbal	Link-16 SISO-J (DIS and HLA)
JADE II JJTTCP	DIS IEEE 1278.1/A HLA IEEE 1516 RPR-FOM V2D17 MaK RTI DLC Compliant	VoIP	Link-16 JREAP Socket-J / SISO-J ?
NATO NMSSP	DIS IEEE 1278.1/A HLA IEEE 1516 RPR-FOM V1 and V2 TENA	No mention	Link-11 and Link-16 SIMPLE and SISO-J
Recommended ADF Corporate Synthetic Range LVC Interoperability Model	DIS IEEE 1278.1/A Entity State PDU Fire/Detonation PDU EE PDU IFF PDU HLA DoD V1.3 or IEEE 1516 equivalent RPR-FOM V2D17 DLC Compliance	DIS IEEE 1278.1/A Transmitter PDU Signal PDU Receiver PDU or HLA RPR-FOM equivalent	Link-16 JREAP SIMPLE SISO-J

The ADF Corporate Synthetic Range Interoperability Model aims to guarantee a minimum (but highly useful) level of "out-of-the-box" corporate LVC interoperability at system delivery and acceptance thus reducing risk and cost to the ADF.

Table 3 The Recommended ADF Corporate LVC Synthetic Range Interoperability Model.

ADF Corporate Synthetic Range Interoperability Model
ADS: DIS IEEE 1278.1/A Entity State PDU Fire PDU Detonation PDU Electromagnetic Emission PDU IFF PDU or equivalent HLA DoD V1.3 or IEEE 1516 DLC Compliance FOM is based on RPR-FOM V2D17
Radio Communications : IEEE 1278.1 Radio Communications Family PDUs Transmitter PDU Signal PDU or the HLA RPR-FOM equivalents
Tactical Data Link : Link-16 JREAP, SIMPLE and SISO-J

Any system that complies with the (full) recommended ADF Corporate Synthetic Range Interoperability Model should be highly interoperable (or should be able to be made highly interoperable using cost-effective COTS or GOTS Gateways) with other similar systems (such as those shown in Table 2) as long as other synthetic environment parameters (Enumerations, Site IDs, etc) are also compliant. These other synthetic environment parameters should, eventually, also become a component of an ADF Corporate Synthetic Range Interoperability Model - see [Zalcman (2003)].

6.2 NATO Interoperability Standards

The NATO Modeling and Simulation Standards Profile (NMSSP) [NATO NMSSP]:

- *Aims to provide guidance to NATO and partner organizations, that have requirements to effectively use modeling and simulation (M&S). No standard is mandated or endorsed by NATO unless there is a related STANAG (NATO Standardisation Agreement) ; and*
- *It maintains information on M&S standards and recommended practices relevant to achieving M&S interoperability and re-use of M&S components such as data, models, etc. The NMSSP provides a set of standards descriptions for decision making on options for the use of M&S standards for NATO activities such as coalition training and experimentation.*

The NATO NMSSP Synthetic Range Interoperability Model (containing interoperability standards of relevance) is shown in Table 4.The standards mentioned in Table 4 are not the only *interoperability* standards supported/discussed in the NATO NMSSP however they are the standards relevant to this current discussion.

Table 4 The NATO NMSSP Synthetic Range Interoperability Model.

NATO NMSSP
ADS: DIS IEEE 1278.1/A HLA IEEE 1516 DLC Compliance FOM is based on RPR-FOM TENA
Radio Communications : No mention
Tactical Data Link : Link-11 and Link-16 SIMPLE and SISO-J

Unfortunately there are (at least) three fundamental flaws in the NATO NMSSP:

- It does not support a complete set of relevant interoperability standards;
- It does not attempt to move towards guaranteeing interoperability – it only provides guidance to reduce risk; and
- It is inconsistent and contradictory.

6.2.1 The NMSSP Does Not Support a Complete Set of Interoperability Standards

The NATO NMSSP lacks standards related to Live simulations such Live radio and the JREAP Link-16 transport protocol.

The NATO NMSSP does not include the JREAP Link-16 transport protocol [MIL-STD-3011]. It should include the JREAP standard otherwise systems that only use interoperability standards recommended in the NATO NMSSP may be restricted to only supporting JTIDS and MIDS Link-16 communications systems (ie no SATCOM systems). The fact that JREAP is not in the NATO NMSSP is a deficiency of the NMSSP - it is not a deficiency in the recommended ADF Corporate Synthetic Range Interoperability Model.

Not supporting JREAP in the NATO NMSSP can be overcome by using a COTS product such as a Northrop Grumman Gateway Manager to translate (ie Gateway) between SIMPLE, SISO-J and JREAP.

The NATO NMSSP does not appear to support LVC Radio Communications interoperability standards as there is no mention of any real radio system standards. The Virtual and Constructive LVC component Radio Communications interoperability standards are covered by the IEEE 1278.1 (ie DIS) Radio Communications PDU Family and their HLA (through the RPR-FOM) (and TENA) equivalents.

6.2.2 The NMSSP Does Not Attempt to Guarantee Interoperability – It Can Only Provide Guidance and Reduce Risk

The NMSSP does not precisely and unambiguously define what is required for LVC interoperability (DIS PDUs, DIS PDU fields, enumerations, etc. - sections 9 and 10) so that each compliant LVC system would be highly interoperable "out-of-the-box"- it simply defines what interoperability standards should be considered. As such the objective of the NMSSP appears to be more to reduce risk rather than attempt to move towards guaranteeing interoperability.

6.2.3 The NMSSP Is Inconsistent and Contradictory

The NATO NMSSP actually contradicts itself in that it supports the use of DIS, HLA and TENA however HLA is a promulgated NATO Standard (STANAG 4603) which means that NATO requires the use of HLA!

The NATO NMSSP also mentions that the results of the recently released US DoD LVC Architecture Roadmap Study [LVCAR-1], [LVCAR-2] were not available for the NMSSP.

The objective of the NATO Modelling and Simulation Standards Profile (NMSSP) is to provide guidance regarding modelling and simulation standards and processes to NATO and partner nations recognising that "one size does not fit all". However the NATO NMSSP should at least contain all the LVC interoperability standards that should be considered when developing a Synthetic Range Interoperability Model.

Even with the interoperability standards recommended, the NATO NMSSP does not recommend or define a minimum level (or any level) of interoperability that all LVC systems should have – it does not recommend a set of standards that should be used – it provides guidance and a list of standards that should be considered. It also does not define individual interoperability standard components precisely and unambiguously. It simply specifies a library of standards that should be selected from when developing a LVC system.

The NATO NMSSP does not recommend PDUs or PDU fields – which the ADF Corporate Synthetic Range Interoperability Model eventually will do. Unless all the relevant "bits and bytes" are unambiguously and precisely defined, a LVC system could be delivered with DIS or (especially) HLA implemented and not be interoperable with other similarly specified LVC systems [Tudor]. The NATO NMSSP only provides limited guidance – it simply reduces risk but it does not move towards guaranteeing interoperability at any level as it does not precisely and unambiguously define what needs to be defined! Exactly how this can be done is discussed in section 9 of this report.

Of the coalition systems analysed the UK LVC systems [Khetia], [Zalcman (2010)] appear to be highly interoperable with the USAF DMO systems as they appear to use very similar (if not identical) interoperability standards – a high level of compliance with USAF DMO interoperability standards is also the intention of the recommended ADF Corporate Synthetic Range Interoperability Model.

6.3 Section Summary

From the literature, Table 2 [Zalcman (2010)] shows the various Synthetic Range Interoperability Models used in recent experiments and exercises.

Any LVC system that is compliant with the recommended ADF Corporate Synthetic Range Interoperability Model (shown in Table 3) should be highly interoperable with the systems shown in Table 2 as long as other relevant synthetic environment parameters such as Enumerations, Site IDs, etc. (which eventually will also become part of the ADF Corporate Synthetic Range Interoperability Model), and appropriate gateways, are also compliant.

The objective of the NATO Modelling and Simulation Standards Profile (NMSSP) is to provide guidance regarding modeling and simulation (M&S) standards and processes to NATO and partner nations [NATO NMSSP].

Unfortunately there are (at least) three fundamental flaws in the NATO NMSSP:

- It does not support a complete set of relevant LVC interoperability standards such as real, operational radio (ie Live radio communications) and the JREAP Link-16 transport protocol;
- It does not attempt to move towards guaranteeing interoperability - it simply provides a list of interoperability standards that should be considered, that is it only provides guidance to reduce risk; and
- It is inconsistent and contradictory in that the NATO NMSSP supports the use of DIS, HLA and TENA however HLA is a promulgated NATO Standard (STANAG 4603) and should therefore be mandated.

7. A Cost-Effective Synthetic Range Interoperability Model for Virtual and Constructive Systems

The recommended ADF Synthetic Range Interoperability Model, as discussed so far, is shown in Table 3. This model addresses interoperability for LVC systems down to the level of specifying what DIS PDUs need to be supported. HLA systems track these PDUs through the use of the HLA RPR-FOM [RPR-FOM-2].

Table 5 The Simplified Virtual and Constructive ADF Corporate Synthetic Range Interoperability Model.

ADF Corporate Virtual and Constructive Synthetic Range Interoperability Model
ADS: DIS IEEE 1278.1/A Entity State PDU Fire PDU Detonation PDU Electromagnetic Emission PDU IFF PDU or equivalent HLA DoD V1.3 or IEEE 1516 DLC Compliance FOM is based on RPR-FOM V2D17
Radio Communications : IEEE 1278.1 Radio Communications Family PDUs Transmitter PDU Signal PDU or the HLA RPR-FOM equivalents
Tactical Data Link : Link-16 encapsulated in SISO-J

For virtual or constructive simulation systems (ie no Live systems) the Synthetic Range Interoperability Model can be simplified further by requiring that only the SISO-J transport protocol [SISO-STD-002-2006] be supported for Link-16 Tactical Data Link interoperability. The model then reduces to that shown in Table 5 and Figure 5 where compliance with this model can be fully achieved using only DIS or HLA. In this situation specialised Tactical Data

Link hardware and software is not required because SISO-J is supported in DIS or HLA thereby (potentially) reducing considerably the software and hardware (ie cost and risk) required for such systems.

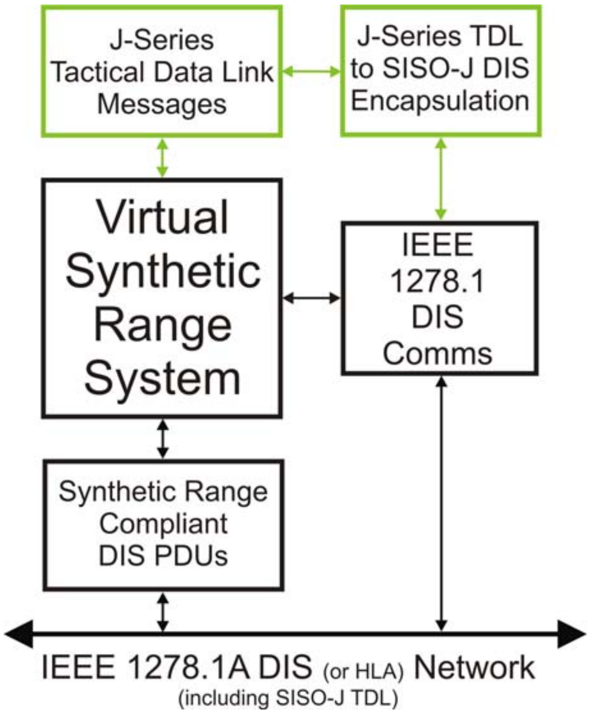

Figure 5 The (Generic) Virtual and Constructive, Synthetic Range Interoperability Model.

This simplified, and more cost-effective, Virtual (and Constructive) Synthetic Range Interoperability Model has been used by DSTO to develop interoperability for the high-fidelity ADGESIM (Air Defence Ground Environment SIM) simulation system (Figure 4) [Zalcman (2009) - 1], [Zalcman (2009) - 2] used by the RAAF to train Air Combat Officers.

This also appears to be the Synthetic Range Interoperability Model supported by the USAF – see Table 2.

Some legacy Virtual and Constructive systems may support Link-16 interoperability but not using the SISO-J TDL transport protocol. Such systems will require access to an appropriate TDL Gateway device, such as a Northrop-Grumman Gateway Manager system, to comply with the Virtual (and Constructive) Synthetic Range Interoperability Model shown in Table 5.

7.1 Section Summary

For virtual or constructive simulation systems (ie no Live systems) the Synthetic Range Interoperability Model can be simplified further by requiring that only the SISO-J transport protocol [SISO-STD-002-2006] be supported for Link-16 Tactical Data Link interoperability. The model then reduces to that shown in Table 5 and Figure 5, where compliance with this model can be fully achieved using only DIS or HLA. In this situation specialised Tactical Data

Link hardware and software is not required because SISO-J is supported both in DIS and HLA thereby reducing considerably the software and hardware (ie cost and risk) required for such systems.

8. How Do We Proceed from Here?

The US DoD LVCAR Study considered five advanced distributed simulation architectures that are in use in the USA. Figure 3 shows the relative use of these architectures in the US as surveyed by the LVCAR Study.

In Australia, although there may be some use of the minor architectures (mainly in COTS systems), the vast majority of distributed simulation systems would be either DIS or HLA systems where:

- DIS: This protocol has a comparatively low barrier to entry; it is relatively simple to learn and easy to use. Also, it imposes a very low overhead. Whenever simulation events do not require using more advanced architectural services (such as time management, region-based information filtering, and so on), DIS offers a very economical solution to the system intercommunication problem [LVCAR – 1], [LVCAR – 2]; and
- HLA: This architecture can serve a disparate collection of simulation systems, including those that require advanced architectural services and those that have modest requirements. In addition to its large US user base, its standing as an international standard has resulted in a large level of use in the coalition partner countries, facilitating combined simulation events that include multiple nations [LVCAR – 1], [LVCAR – 2].

However also according to the LVCAR Study

> *"DIS should only be considered as a candidate for limited convergence. This protocol provides unique services and capabilities that would be lost were the protocol to be fully converged with other architectures that serve different communities and necessarily provide higher levels of service capability. While some of the activities that could lead to more service-level compatibility (e.g., common, components of object models, standard wire-level protocols, etc.) between DIS and the other architectures will prove advantageous,* ***<u>DIS should remain much as it is today</u>****, a lightweight, core capability protocol";*

Of the five initial, potential LVCAR strategies two were finally recommended:

- **Actively Manage the Existing Architectures** - Create standard inter-architecture integration solutions. Keep the current multiple architectures but invest in improving the construction / performance / integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper"; and

- **Convergence** - Create policy and procedures, and provide small amounts of seed money, to encourage the architectures to converge with one another in the long-term time frame (e.g., 10 years). When they become so similar in features and capabilities, engineer the merging of them into a single architecture.

Therefore because the vast majority of LVC systems in Australia will be DIS or HLA; and ***DIS should remain much as it is today***, the LVCAR **Convergence** strategy cannot really apply in Australia. In Australia DIS and HLA will remain as two separate architectures / protocols - both DIS and HLA need to be supported.

However the LVCAR **Actively Manage the Existing Architectures** strategy "*to invest in improving the construction/performance/integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper*" can apply in Australia.

This current report focuses on the common object model component of the **Actively Manage the Existing Architectures** LVCAR Study strategy. Unless LVC systems have such common object models (ie common data) gateways, translators, etc. will not be able to work as there will be no common data for translators or gateways to work on!

8.1 The DIS (Common) Object Model

In DIS it is the DIS Protocol Data Unit (PDU) that is the main component of the DIS "object model".

The structure of DIS PDUs (the PDU data fields) and how (ie the format) the data is packed into these PDU data fields is defined in the IEEE DIS standards – the latest relevant standards are the IEEE 1278.1 standard [DIS (1995)] and the incremental 1278.1 upgrade – the IEEE 1278.1A standard [DIS (1998)].

The DIS PDU is transmitted around a network encapsulated in a higher level standard computer internet network packet/protocol known as UDP (User Datagram Protocol). Therefore the format of any particular DIS PDU on the network is fixed – it is the same for all DIS applications and the structure, and the format, of the DIS PDU is what is actually defined in the IEEE DIS standards – all DIS programs "speak the same language"! Because the DIS PDU data on the network (ie the "wire") is always structured in the same way (ie as defined in the IEEE DIS standards) DIS is sometimes referred to as a "wire standard".

Because DIS is a wire standard DIS applications from different manufacturers can interoperate as long as they support IEEE standard DIS PDUs, and populate the same fields in the same PDUs with the same common set of enumeration data.

A new version of the DIS standard (to be known as IEEE-1278-2011) is due to complete its IEEE balloting process (actually carried by SISO – the Simulation Interoperability Standards Organization [SISO]) in 2011. According to Ryan et al. [Ryan] the proposed new IEEE-1278-2011 standard is an extensive revision that clarifies ambiguities present in the current standard, adds new capabilities that reflect changes in military equipment and doctrine, and provides for advances in technologies such as the Internet, mobile telephony, computing and the widespread use of the Global Positioning System for positional and time data.

8.2 Common Architecture / Protocol Independent Enumerations

The data that populates the DIS PDUs (ie the data present in the DIS PDU data fields) is defined in another (SISO) standard "Enumeration and Bit Encoded Values for Use with Protocols for Distributed Interactive Simulation (ie DIS) Applications" [SISO-REF-010]. This standard is also in the process of being updated and the new 2010 version of the Enumerations Document standard will be referred to as SISO-REF-010-2010. When released this standard should be available from the SISO web site [SISO-REF-010].

Although the title of the Enumerations Data standard refers specifically to its use for DIS systems the enumerations are widely used in other architecture / protocol LVC systems (eg. HLA, TENA). If this approach was not adopted each architecture or protocol would have its own enumeration standard and (even more complex) protocol translators and gateways would be required to provide interoperability between the different distributed simulation architectures and protocols.

8.3 The HLA (Common) Object Model

A HLA simulation system (known as a Federation) is comprised of several HLA simulators/simulations (Federates) interoperating with each other, and with other Federations. The HLA Federates interoperate with each other through the HLA Run-Time Infrastructure (RTI). The RTI provides a standard Application Programmers Interface (API) - a standard programming interface which enables HLA Federates to interoperate through API calls to the HLA RTI. The HLA RTI APIs are defined in an IEEE standard such as IEEE 1516.1 [HLA (2000) – 2].

This why HLA is sometimes referred to as an "API standard" because the HLA software is always structured in the same way (makes the same structured RTI API calls) as defined in the relevant HLA standard. You can therefore re-use HLA software with different manufacturers RTIs.

However HLA RTIs are produced by industry (and military) and how HLA packets appear on the network is not defined – this information is proprietary. HLA is an "API standard" not a "wire standard" and HLA applications that do not use exactly the same version of the same manufacturer's HLA RTI are not guaranteed to interoperate – they do not "speak the same language"! Therefore you can re-use HLA software but only if all Federates and Federations use the same manufacturer's RTI.

HLA Federations that use different RTIs may require specifically designed Bridges to interoperate. Federation HLA interoperability can be extremely complex (and difficult) [Tudor]!

HLA is more flexible than DIS. However this additional flexibility comes at the cost of additional complexity, difficulty, and possibly cost, when making HLA Federations interoperable. How the data is structured (defined in the HLA object model) is determined by the HLA application developer and is known as the HLA Federation Object Model (FOM). A

Federation Object Model is a specification defining the information exchanged between federates at runtime (ie) and includes object classes, object class attributes, interaction classes, interaction parameters and other relevant information [RPR-FOM-1].

Each HLA Federate has its own Simulation Object Model (SOM) that defines the object model for that particular Federate. A SOM specifies the types of information that an individual federate can provide to, and receive from (known as publish and subscribe in HLA terminology), other federates in HLA federations.

During the development of HLA the concept of a Reference FOM was developed. The goal of a Reference FOM is to enhance *a-priori* interoperability by specifying content standards for common capabilities. Building upon the Reference FOM (where each federation's changes only extend this core Reference FOM's functionality) to meet the needs of a given HLA execution creates the FOM for a particular federation [RPR-FOM-1].

The Real-time Platform Reference Federation Object Model (RPR-FOM, pronounced "reaper fom") was specifically designed to support interoperability between DIS and HLA systems and enhance a-priori interoperability among HLA RPR-FOM users (see section 3.2.3).

Like DIS, the RPR FOM is designed to support real time simulations of discrete physical entities such as planes, ships, soldiers, munitions, etc. These simulations are considered "real-time" because each second of elapsed execution time is equivalent to one second of time in the virtual world. Real-time, platform simulations are often used to support man-in-the-loop or hardware-in-the-loop systems [RPR-FOM-1].

Version 1.0 of the RPR-FOM provides a HLA translation path for the DIS capabilities defined in IEEE 1278.1 [DIS (1995)] standard. Version 2 of the RPR-FOM was meant to add the functionality of the IEEE 1278.1A standard [DIS (1998)]. However RPR-FOM Version 2 was never "standardized".

This is why all the Synthetic Range Interoperability Model tables (eg the recommended ADF Corporate Synthetic Range Interoperability Model described in Table 3) refer to the HLA RPR-FOM as this HLA FOM provides support for the HLA equivalent of DIS.

This report will focus specifically on DIS interoperability. However interoperability between DIS and RPR-FOM based HLA LVC systems can be provided by DIS/HLA Gateways whose HLA FOM is based on the HLA RPR-FOM. Such DIS/HLA Gateways can be purchased as COTS products from RTI manufacturers eg the MaK Technologies [MaK] DIS/HLA Gateway product enables interoperability between IEEE 1278.1A and HLA LVC systems (using the Mak Technologies HLA RTI and the RPR-FOM).

HLA interoperability is complex and exactly how HLA (and HLA and DIS) systems interoperate depends on whether source code is available, which manufacturer's RTI has been used, which FOM has been used, and which version of HLA (US DoD V1.3, IEEE 1516, HLA Evolved) has been used [Tudor].

8.4 Section Summary

The LVCAR Study investigated five potential strategies (section 4.5):

- **Status Quo or "Do Nothing";**

- **Actively Manage the Existing Architectures;**
- **Convergence;**
- **Select One of the Existing Architectures; and**
- **Develop A New Architecture.**

Of these five initial, potential LVCAR strategies two were finally recommended:

- Actively Manage the Existing Architectures - Create standard inter-architecture integration solutions. Keep the current multiple architectures but invest in improving the construction / performance / integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper"; and
- Convergence - Create policy and procedures, and provide small amounts of seed money, to encourage the architectures to converge with one another in the long-term time frame (e.g., 10 years). When they become so similar in features and capabilities, engineer the merging of them into a single architecture.

The US LVCAR Study found that five advanced distributed simulation architectures are commonly in use in the US – see Figure 3.

In Australia the vast majority of distributed simulation systems would be either DIS or HLA systems where:

- DIS - has a low barrier to entry; is simple to learn and easy to use; and imposes a very low overhead. Whenever simulation events do not require the use of more advanced architectural services DIS offers a very economical solution to interoperability [LVCAR – 1], [LVCAR – 2]; and
- HLA - can serve a disparate collection of simulation systems including those that require advanced architectural services and is in considerable use in the US and in the coalition partner countries [LVCAR – 1], [LVCAR – 2].

Because the LVCAR Study recommends that ***DIS should remain much as it is today***, the **Convergence** strategy cannot really apply in Australia and DIS and HLA will need to remain and be supported as two separate architectures / protocols.

However the LVCAR **Actively Manage the Existing Architectures** strategy "*to invest in improving the construction/performance/integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper*" can apply in Australia.

In DIS the DIS Protocol Data Unit (PDU) is a main component of the DIS "object model". The structure of DIS PDUs (the PDU data fields), and how the data is packed into these PDU data fields, are defined in the IEEE 1278.1 standard [DIS (1995)] and the incremental (ie upgrade) IEEE 1278.1A standard [DIS (1998)]. A new version of the DIS standard (IEEE-1278-2011) is due to complete its IEEE balloting process in 2011.

HLA is more flexible than DIS. However this flexibility comes at the cost of complexity (and most likely financial cost) when making HLA Federations interoperable. The HLA object model is determined by the HLA Federation developer and is known as the HLA Federation Object Model (FOM). A Federation Object Model is a specification defining the information exchanged between federates at runtime and includes object classes, object class attributes, interaction classes, interaction parameters and other relevant information [RPR-FOM-1]. Each HLA Federate has its own Simulation Object Model (SOM) that defines the object model for the Federate. A SOM specifies the types of information that an individual federate can provide to, and receive from, other federates in HLA federations.

The Real-time Platform Reference Federation Object Model (the RPR-FOM) was designed to support and enhance a-priori interoperability between DIS and HLA systems built on the HLA RPR-FOM (see section 3.2.3) as a starting point. This report will focus specifically on DIS; however interoperability between DIS and RPR-FOM based HLA LVC systems can be provided by COTS or GOTS DIS/HLA Gateways.

A list of common SISO standard [SISO-REF-010], protocol independent enumerations can be specified to be delivered with all ADF LVC systems – see section 10.3 also.

9. What Exactly Does "Compliance With a Synthetic Range Interoperability Model" Mean?

9.1 An Interoperability Standards Based Approach

Interoperability among LVC systems within a common scenario requires compliance with an agreed set of interoperability standards including network infrastructure, data, interoperability protocols, platform / environmental representation, etc [Aldinger]. This requires the development of a Synthetic Range Interoperability Model (a set of (LVC) interoperability standards) that is a crucial part of any synthetic range architecture. All synthetic range systems that are compliant with such a Synthetic Range Interoperability Model should be highly interoperable regardless of whether the systems are Live, Virtual or Constructive.

Participants in USAF Distributed Mission Operations (DMO) training events must use systems and processes that comply with USAF DMO interoperability standards. They must be certified (ie accredited) for participation (ie comply with DMO standards) before being able to begin system integration activities on the DMO Network. All DMO systems must adhere strictly to this rigid set of interoperability standards and processes. This standards based approach architecture has been developed to provide a high-reliability, routine, robust, scalable and reliable, global Virtual-Constructive, daily training capability for the war-fighter [Aldinger].

The US Army's LVC Integrating Architecture (LVC-IA) is also moving towards this same approach of developing interoperability and integration standards, guidelines and processes with the objective of introducing this standards-based approach back into the US Army's base programs [Lyders].

9.2 A Synthetic Range Interoperability Model Must Be A Mandated Model!

All specifications defined in a Synthetic Range Interoperability Model must be mandated - all specifications (DIS PDUs, PDU fields, enumerations data, etc.) in a Synthetic Range Interoperability Model must be implemented in a LVC system that intends to comply with that particular Synthetic Range Interoperability Model.

Once a Synthetic Range Interoperability Model has been precisely and unambiguously defined, common RFT specifications and common associated test and acceptance procedures for that particular Synthetic Range Interoperability Model can be developed [Ross].

9.3 Only Accredited Systems Can Participate In LVC Activities

The same RFT specifications, and associated test and acceptance procedures will be used to specify and test any LVC system that is to comply with that particular Synthetic Range Interoperability Model.

Once a LVC system has been tested against the specifications of that particular Synthetic Range Interoperability Model, thereby determining that the system complies with all the standard requirements of that particular Synthetic Range Interoperability Model, the system receives accreditation that it complies with that particular Synthetic Range Interoperability Model.

> ***Accreditation*** *is a process in which certification of competency, authority, or credibility is presented.*
>
> *Organizations that issue credentials or certify third parties against official standards are themselves formally accredited by accreditation bodies (such as IEEE); hence they are sometimes known as "accredited certification bodies". The accreditation process ensures that their certification practices are acceptable, typically meaning that they are competent to test and certify third parties, behave ethically and employ suitable quality assurance.* [Accreditation]

A LVC system cannot participate (ie begin system integration activities) in a LVC activity unless that LVC system has been certified (ie has received accreditation) for participation (ie is compliant with the Synthetic Range Interoperability Model specified for use) in that particular activity or exercise.

9.4 A Synthetic Range Interoperability Model Is A Minimalistic Model!

> *"Minimalism describes movements in various forms of art and design where the work is stripped down to its most fundamental features."[Minimalism]*

Systems compliant with the Synthetic Range Interoperability Model specified in Table 3 can exceed or enhance the interoperability (standards) specified. For example a high-fidelity, Frigate LVC system would most likely support a Sonar (Underwater Acoustic) capability in addition to the Synthetic Range Interoperability Model specified in Table 3. The DIS

Underwater Acoustic PDU is not part of the Synthetic Range Interoperability Model specified in Table 3 because Table 3 defines an (minimalistic) ADF Corporate Synthetic Range Interoperability Model. An Army M1A1 Abrahams tank or a F/A-18 fighter has no requirement for any Underwater Acoustic capability!

However, a DIS Underwater Acoustic PDU would most likely be part of a Royal Australian Navy Synthetic Range Interoperability Model which would be built upon the ADF Corporate Synthetic Range Interoperability Model.

Compliance with a Synthetic Range Interoperability Model does not restrict what additional interoperability a compliant system can support. However, compliance does require support for a minimum set of interoperability components / capabilities (eg PDUs for DIS) specified in the particular Synthetic Range Interoperability Model.

9.5 Compliance With A Synthetic Range Interoperability Model Does Not Mean That All Specified PDUs Are Always Supported!

Interoperability (from a DIS point-of-view) with the ADF Corporate Synthetic Range Interoperability Model shown in Table 5 can be alternatively specified as shown in Table 6.

Table 6 An Alternative (DIS) View of the Simplified ADF Virtual and Constructive Corporate Synthetic Range Interoperability Model as described in Table 5.

ADF Corporate Virtual and Constructive Synthetic Range Interoperability Model	
DIS PDUs	**Data Functionality**
Entity State PDU	Entity Information
Fire PDU	Weapon Information
Detonation PDU	Weapon Information
Electromagnetic Emission PDU	Sensor Information
IFF PDU	IFF Information
Transmitter PDU	Radio Communications Information
Signal PDU	Radio Communications Information
Transmitter PDU (SISO-J)	Tactical Data Link Information
Signal PDU (SISO-J)	Tactical Data Link Information

However compliance with a specific Synthetic Range Interoperability Model **does not mean that all the specified PDUs are always supported**. For example, if a high-fidelity, simulation system for a single-engine, Cessna 172 “Skyhawk” aircraft (shown in Figure 6 and used by some military forces) were to be developed, compliance with the Synthetic Range Interoperability Model, as shown in Tables 5 and 6, would be as is shown in Table 7 because a Cessna 172 aircraft has:

- No weapons therefore support for transmission of the Fire and Detonation PDUs is not required. However support for the reception of Detonation PDUs is (may be) required to determine any damage resulting from the detonation of a weapon – see below;
- No radar sensor system therefore support for the Electromagnetic Emission PDU is not required; and
- No tactical data link system therefore support for the SISO-J capability of the Transmitter and Signal PDUs is not required.

Figure 6   A Cessna 172 Skyhawk aircraft which is used by some Military Forces

The DIS PDUs that should be supported in a Cessna 172 LVC system that comply with the ADF Corporate Synthetic Range Interoperability Model are shown in Table 7.

As long as the high-fidelity LVC system for the Cessna 172 "Skyhawk" aircraft supports appropriate interoperability for the Entity State, IFF, Transmitter and Signal PDUs, it would be considered as being compliant with the Synthetic Range Interoperability Model as described in Tables 5 and 6.

However, any system that has weapons, a sensor system, radio communications and a Link-16 tactical data link capability should support all the DIS PDUs (or their HLA RPR-FOM equivalents) as shown in Tables 5 and 6.

A Cessna 172 does not (normally) carry any weapons and would therefore not need to transmit any Fire and Detonation DIS PDUs into the distributed simulation network. However in DIS it is the responsibility of every DIS system to determine if any exploding weapons have any effect on their ownship system. Therefore all DIS LVC systems (including our Cessna 172 LVC system) must (should) be able to detect a Detonation PDU and determine if there would be any damage to the ownship system (our Cessna 172 LVC system) by examining the data from the Detonation PDU.

If our Cessna 172 LVC system did not support this capability a direct hit with a virtual weapon (eg missile) would have no effect!

9.6 Section Summary

Interoperability between LVC systems within a common scenario requires compliance with an agreed set of interoperability standards including network infrastructure, data, interoperability protocols, platform / environmental representation, etc. This requires the development of a Synthetic Range Interoperability Model (a set of interoperability standards) that is a crucial part of any synthetic range architecture. All synthetic range systems that are compliant with a particular (ie corporate ADF) Synthetic Range Interoperability Model should be highly interoperable (with each other) regardless of whether the systems are Live, Virtual or Constructive.

Table 7 Synthetic Range Interoperability Model Compliance Requirement for a Cessna 172 aircraft.

Synthetic Range Interoperability Model Compliance Requirement for a Cessna 172	
DIS PDUs	**Data Functionality**
Entity State PDU	Entity Information
Fire PDU	No Weapons Capability – not required
Detonation PDU	Receive Only Detonation PDU to Determine Ownship Damage
Electromagnetic Emission PDU	No Sensor System Capability – not required
IFF PDU	IFF Information
Transmitter PDU	Radio Communications Information
Signal PDU	Radio Communications Information
Transmitter PDU (SISO-J)	No Tactical Data Link interoperability – not required
Signal PDU (SISO-J)	No Tactical Data Link interoperability – not required

This "Standards Based Approach" architecture will provide a high-reliability, routine, robust, scalable and reliable, global, LVC, daily training capability for the war-fighter. The USAF Distributed Mission Operations (DMO) capability is based on this standards based approach philosophy [Aldinger].

All specifications defined in a Synthetic Range Interoperability Model must be mandated!

Once a Synthetic Range Interoperability Model (ie interoperability standards) has been precisely and unambiguously defined, common RFT specifications and test and acceptance procedures to enable accreditation for that particular Synthetic Range Interoperability Model can be developed.

LVC systems cannot participate in exercises unless appropriate accreditation has occurred.

Compliance with a Synthetic Range Interoperability Model does not restrict additional enhancements for specific LVC systems.

10. How Do We Precisely and Unambiguously Define What Needs to be Defined in a Corporate Interoperability Standard?

10.1 Mandated DIS PDUs

Tables 3, 5 and 6 specify recommended ADF LVC and VC Synthetic Range Interoperability Models at the DIS PDU level. These tables specify which DIS PDUs all compliant systems must support (subject to the discussion in section 9.4). Support for all specified PDUs included in the Synthetic Range Interoperability Model must be mandated otherwise support for every PDU is not precisely and unambiguously determined.

Although defining specifically which DIS PDUs each LVC system must support is beginning to precisely and unambiguously define what information each LVC system needs to disseminate and know about, defining an interoperability model at the PDU level is not sufficient. It is however starting to move from a reducing risk approach towards a guaranteeing interoperability approach. However it still does not precisely and unambiguously define the required LVC system data!

10.2 Mandated DIS PDU Data Fields

For each DIS PDU specified in an ADF Synthetic Range Interoperability Model, mandatory fields within each specified PDU must also be specified. This indicates to every Synthetic Range Interoperability Model compliant LVC system which fields in which DIS PDUs must be precisely and unambiguously populated with standardised data.

Compliant systems must interoperate appropriately (ie correctly) with appropriately specified data in these specified and mandated DIS PDUs and DIS PDU data fields.

Compliant systems must appropriately (ie correctly) populate the specified and mandated DIS PDU fields with appropriately specified data when transmitting the specified DIS PDUs into the distributed simulation network.

However when receiving DIS PDUs, compliant systems will then also unambiguously and precisely understand the meaning of (ie understand how to appropriately interoperate with) appropriately specified data detected in the specified and mandated DIS PDU fields.

The structure and the format of each DIS PDU, and each data field within the specific DIS PDU, is defined by the appropriate IEEE DIS Standard [DIS (1995)], [DIS (1998)].

A Synthetic Range Interoperability Model would define (ie document) which DIS PDUs are mandated and need to be supported – as in Tables 3, 5 and 6.

A Synthetic Range Interoperability Model would also define which PDU data fields must be mandated for each mandated DIS PDU.

Table 8 shows the format of some of the data fields contained in the DIS Entity State PDU as specified in the appropriate IEEE DIS Standard [DIS (1995)].

The Entity State Protocol Data Unit (PDU) exists to communicate information about an entity's state so that a receiving simulation application can appropriately represent the entity within the simulation application. Defining what entity is being represented by the Entity State PDU is a fundamental objective of the Entity State PDU [DIS (1995)].

The type of entity described in a DIS Entity State PDU is described by the data found in the Entity Type record contained within it [DIS (1995)] – bottom of Table 8. The fields found in the Entity Type record are as follows:

Table 8 Format of Some of the Data Fields in the DIS Entity State PDU.

Field size (bits)	**Entity State PDU fields**	
96	PDU Header	Protocol Version—8-bit enumeration
		Exercise ID—8-bit unsigned integer
		PDU Type—8-bit enumeration
		Protocol Family—8-bit enumeration
		Timestamp—32-bit unsigned integer
		Length—16-bit unsigned integer
		Padding—16 bits unused
48	Entity ID	Site—16-bit unsigned integer
		Application—16-bit unsigned integer
		Entity—16-bit unsigned integer
8	Force ID	8-bit enumeration
8	Number of Articulation Parameters (*n*)	8-bit unsigned integer
64	Entity Type	Entity Kind—8-bit enumeration
		Domain—8-bit enumeration
		Country—16-bit enumeration
		Category—8-bit enumeration
		Subcategory—8-bit enumeration
		Specific—8-bit enumeration
		Extra—8-bit enumeration

- Entity Kind: identifies the kind of entity such as a platform, a munition, a life form, etc.;
- Domain: specifies the domain in which the entity operates. For platform entities the set of entity domains are other, land, air, surface, subsurface and space. Domains depend on the entity kind;
- Country: specifies the country to which the design of the entity is attributed. For example the country code of the US used in this field is 225, the country code for Australia is 13;
- Category: specifies the main category that describes the entity. Some examples of categories for the air domain are Fighter/Air Defence, Attack/Strike, Bomber, etc.;
- Subcategory: specifies a particular subcategory to which an entity belongs based on the Category field. Some examples here for an Air Domain Fighter/Air Defence Category are F-16, F-15, F-22, F/A-18, etc.;
- Specific: Further defines specific information about a Subcategory entity such as an F/A-18A, an F/A-18B, etc.; and
- Extra: contains extra information to describe a particular entity.

The entity information is usually presented in the numeric form Kind : Domain : Country : Category : Subcategory : Specific : Extra where the enumeration 1:2:225:1:9:1:0 (or 1:2:225:1:9:1) represents a USA designed, F/A-18A aircraft.

Mandating DIS PDU data fields indicates to compliant systems that (some of) the data present in these fields will be precisely and unambiguously known or defined. It will then be the responsibility of compliant LVC systems to appropriately interoperate with that data found in these mandated DIS PDU data fields.

10.3 Mandated DIS PDU Data Field Enumerations Data

The actual data contained within the DIS PDU data fields are known as enumerations and can be found in a SISO standard titled "Enumeration and Bit Encoded Values for Use with Protocols for Distributed Interactive Simulation (ie DIS) Applications" [SISO-REF-010]. The latest version of this standard is always available from www.sisostds.org.

A set of standard enumerations (from the SISO-REF-010 document) that will define a minimum known set of enumerations data for every mandated DIS PDU data field in every mandated DIS PDU must still be defined!

When an enumeration is specified for an LVC system, that LVC system may have to have a visual database model developed, a behavioural model developed, a sensor model developed, etc. It can add considerable cost to support specific enumerations – especially after the LVC system has been accepted by the Commonwealth. This is why a common ADF corporate standard enumerations set, (pre-)defined at tender specification time for all ADF LVC systems, should reduce cost because all compliant ADF LVC systems will be interoperable with the standard enumerations set at delivery ie "Out-Of-The-Box"! Some standard enumeration set data (eg a visual model of an ADF F/A-18) may be reusable between compliant LVC systems.

However not all enumeration data that will be found in the standardised DIS PDU data fields will be included in the standard ADF Corporate Enumerations set as this would force all compliant LVC systems to support enumerations that may only be of interest to a small group or number of LVC systems. If such enumerations were to be included in an ADF Corporate Standard Enumerations Set this would most likely add considerable, unnecessary cost as most compliant LVC systems may never require the use of such enumerations but a visual database model may have to be developed, a behavioural model may have to be developed, a sensor model may have to be developed, etc. for every enumeration for every compliant LVC systems. The standard ADF Corporate Enumerations set must be well thought out and as long as all Joint and Coalition scenarios use enumerations from this standard ADF Corporate Enumerations set, "Out-Of-The-Box" interoperability should be very high!

Therefore the ADF Corporate Synthetic Range Interoperability Model will contain documentation that defines what DIS PDUs must be mandated, what DIS PDU data fields must be mandated for each mandated DIS PDU (eg the Entity State PDU Entity Type record data fields), and it will also contain a standard set of ADF Corporate Synthetic Range Interoperability Model enumerations that define exactly what mandated standard enumeration data may be found in the mandated DIS PDU data fields.

The PDUs, PDU data fields, and the standard set of ADF Corporate Synthetic Range Interoperability Model enumerations must be mandated for all compliant LVC systems otherwise a high level of "Out-Of-The-Box" interoperability cannot be guaranteed. In the USAF DMO system, LVC systems cannot begin network integration activities (ie join the DMO network to participate in a distributed exercise) unless the systems have been accredited – that is they have been tested and certified as being compliant with all the required DMO interoperability standards.

10.4 Section Summary

All relevant Synthetic Range Interoperability Model parameters (eg DIS PDUs, DIS PDU data fields (or their HLA equivalents), enumerations and any other relevant parameters must all be mandated for "Out-The-Box" interoperability to be maximised.

11. How Does DSTO Proceed From Here?

The USA DoD LVCAR Study fundamental precept #4 (section 4.3) suggests that a centralised management team (which is corporately funded) is necessary to prevent divergence; to enable the architecture convergence strategy; and to have influence on future LVC architecture development activities (ie the development of corporate interoperability standards), via funding decisions, on the organisations that evolve existing architectures. Without such centralised management and funding, existing architecture communities (eg DSTO Divisional communities) will continue to operate in line with their own self-interests, and the broader corporate LVC interoperability needs of the organisation (eg DSTO) will be treated as secondary issues, that are likely to continue to be ignored as concerns that are not relevant to higher priority, locally funded problems. Unless corporate interoperability development work is centrally managed (ie tasked and resourced), corporate interoperability development may not occur, or if it did, it would only occur in an unsatisfactory ad-hoc fashion (section 5.3.4).

The LVCAR Study fundamental precept #2 (section 4.3) states that interoperability is not free - it needs to be appropriately resourced. It may be difficult to justify and accurately quantify a return on investment in LVC interoperability however it is also unreasonable to expect that LVC interoperability can be achieved with little or no investment.

Therefore the LVCAR Study fundamental precepts 2 and 4 infer that interoperability work should be centrally managed and appropriately funded.

In AOD there are two programmes of work that could, and already do to some extent (eg this report), contribute to the development of ADF corporate interoperability standards: the proposed AOD (USAF) DMO compliant, Mission Training Centre (MTC), Capability Concept Demonstrator (CCD) [Zalcman (2010)]; and the DSTO Net Warrior initiative [Filippidis].

11.1 An AOD Mission Training Centre Capability Concept Demonstrator

A (USAF) DMO compliant, Mission Training Centre (MTC), Capability Concept Demonstrator (CCD), to be developed by AOD, has been proposed [Zalcman (2010)].

The DSTO Air Operations Division has sufficient simulation system components, expertise and experience to develop such a DMO compliant MTC CCD, similar to that developed by the UK MOD MTDS (Mission Training through Distributed Simulation) programme [Khetia].

The objectives of this AOD MTC CCD will be:

- To study various elements of Joint and Coalition synthetic Live-Virtual-Constructive (LVC) training to provide guidance on technical and operational issues to assist the RAAF to migrate towards a highly interoperable, LVC corporate synthetic environment (Synthetic Range) to enable a training focused, DMO compliant RAAF MTC proposal to be developed;

- To do experimentation, research and development to help the ADF and RAAF develop corporate interoperability standards based on the USAF DMO standards. These standards, to be known collectively as the ADF Corporate Synthetic Range Interoperability Model, will form the advanced distributed simulation infrastructure (i.e. the standards based approach) upon which the AOD MTC CCD (and therefore the RAAF MTC) will be developed. The objective of this work is to reduce risk and cost when acquiring future corporate ADF LVC components, training systems and operational platforms with LVC capabilities; and

- To test, evaluate and/or develop re-usable LVC components (Blue, Red and White Forces CGF applications, Loggers, After-Action-Review applications, etc) which could be used (and re-used) to reduce cost and risk for current and future ADF and RAAF operational platforms, and training and experimentation systems with LVC interfaces.

Some sample NATO "Use Cases" involving LVC systems given to illustrate the importance of integrating Live Simulation (section 2.3.4) in both training and simulation environments [Gustavsson] include:

- Extended Air Defence Simulation - Several types of real operational sensors (radar) airborne/ground-based Air Defence systems fed with a synthetic environment including aircraft and ballistic and cruise missiles;
- Composite Air Operations - Large numbers of aircraft and air/ground defence to be able to attack certain targets. In the future this could include live aircraft and sensors including AWACS with real pilots/real operators;
- Close Air Support/Indirect Fire Support - Training of the Forward Air Controller/ Forward part in a live environment; and
- Training In Real C2 System Environments - In many training and simulation systems where real operational C2-systems interoperate with other live operational systems.

RAAF Air Battle Management (ABM) teams are responsible for the tactical command and control of all air assets in the battlespace and are typically comprised of a Tactical Director and a number of Fighter Controllers. The Tactical Director allocates assets and manages operations within the air battle, overseeing and directing the Fighter Controllers, and communicates with other command elements and external agencies. The Fighter Controllers liaise with pilots in order to direct aircraft in accordance with instructions, procedures, the tactical plan, and as directed by the Tactical Director [Shanahan].

Some AOD simulation systems that could support the above example Use Cases and could form the basis of a DMO compliant, AOD Air Battle Management, MTC CCD include:

- A Ground Based Air Defence system - The Air Defence Ground Environment SIMulator (ADGESIM) is the actual high-fidelity training system (ie it stimulates the real, operational software used by the RAAF) used to train RAAF Air Combat Officers (developed at DSTO);
- A Fighter Aircraft system - The Deployable Aircraft Cockpit Simulator (DACS) is being developed at the AOD Air Operations Simulation Centre (AOSC); and
- An Airborne Early Warning & Control (AEW&C) aircraft (AWACS like aircraft referred to as Wedgetail) system – The Wedgetail Integration and Research Environment (WIRE) is a high-fidelity representation (it is a stimulated, real operational AEW&C mission software system) of the user interface used in the real RAAF AEW&C aircraft.

An AOD, Air Battle Management, Mission Training Centre Task should be developed within AOD as the ADGESIM, DACS and AEW&C WIRE systems are all AOD systems. One of the problems with Net Warrior is that inter-Divisional LVC simulation systems interoperability is not directly funded and neither is it high priority for individual DSTO Divisions. Inter-Divisional LVC simulation system interoperability is generally treated as low priority and this impedes (LVC interoperability) progress considerably – this is why it is important (and also very convenient) that the systems under development in the AOD MTC CCD proposal are all managed and funded by AOD (see section 5.3.4) thus learning the lessons as described by the LVCAR Study precept # 4 (sections 4.3.4 and 5.3.4).

The first step to building such a capability is to further develop an appropriate ADF Corporate Synthetic Range Interoperability Model (ie the required interoperability standards) and to then develop the AOD ADGESIM, DACS and the AEW&C WIRE systems to be compliant with this Synthetic Range Interoperability Model ie to be LVC interoperable.

These AOD systems can then be connected over the persistent, classified (DSTO Net Warrior) network that has already been (or will shortly be) developed as part of the Net Warrior initiative [Foster], [Sioutis].

It is the intention of the authors of this report to produce a DSTO Report on the development of an AOD Air Battle Management Mission Training Centre in the near future.

11.2 The DSTO (AOD) Net Warrior Initiative

The DSTO Net Warrior initiative was conceived to address, through experimentation, new and evolving network centric capabilities and mission system technologies to enhance ADF joint war fighting capabilities [Foster], [Sioutis]. With this as the prime objective, Net Warrior will be in part the realisation of a general ambition in DSTO to create a research network of (NCW enabled) Battlelabs [Filippidis].

Initially, the Net Warrior initiative has developed a persistent network infrastructure to support a research capability in NCW by connecting a set of nodes which are test-beds representing current or potential future ADF assets [Lawrie], [Zalcman (2006)], [Zalcman (2007)], [Zalcman (2008)].

The nodes were selected using the criteria of:

- The need for interoperability of the real assets;
- The significance of the real assets in joint operations;
- Whether high fidelity representations of the assets exist or are planned in DSTO; and
- Whether experimental representations of potential assets would benefit from participating.

High fidelity test-beds allow evaluation of real systems and investigation of relevant technical and operational issues. The DSTO nodes will be high fidelity representations of airborne and maritime assets and will include AEW&C, ADGE and a future ship. These nodes already exist, in some form, but at present are not able to appropriately interoperate with each other.

Net Warrior interoperability standards do not currently exist. This current report is part of the work to develop such Net Warrior interoperability standards.

The test-beds will evolve in themselves as integral components of the Net Warrior network and as stand-alone components of research capabilities with platform centric research objectives. Where there is common interest, exercises will be run which involve all nodes or a subset of these nodes.

The Air Defence Ground Environment SIMulator (ADGESIM) [Blacklock (2006)], [Blacklock (2007)], [Zalcman (2005)], [Zalcman (2006)], [Zalcman (2008)], [Zalcman (2009) - 1], [Zalcman (2009) – 2] the Deployable Aircraft (i.e. F/A-18) Cockpit Simulator (DACS) systems, and the AEW&C High-Fidelity WIRE (Wedgetail Integration and Research Environment) simulation system are all being developed and/or deployed within DSTO's Air Operations Division. Multiple instances of ADGESIM and the WIRE already exist in branches of AOD.

Both the ADGESIM and WIRE systems are based on real operational components - they are high fidelity, stimulated systems.

The ADGESIM (Air Combat Officer) simulation system (which is used by the RAAF to train RAAF Air Combat Officers – see Figure 4) is fully compliant with the (proposed) ADF Corporate Synthetic Range Interoperability Model shown in Table 3 – at least down to the PDU level.

The DACS and WIRE systems are also being continuously developed towards being compliant with the Table 3 Synthetic Range Interoperability Model. An objective of Net Warrior is to support USAF DMO compliant interoperability. The development of such a set of DMO compliant interoperability standards will accelerate the development of coalition DMO compliance for the DACS and WIRE systems.

Once these DSTO AOD simulation systems are all compliant with such a set of appropriate interoperability standards (eg a Net Warrior Synthetic Range Interoperability Model) the AOD ADGESIM, DACS and WIRE (LVC) systems should all be highly interoperable with each other and with other similarly compliant LVC systems.

Since it is assumed that the Synthetic Range Interoperability Model defines a set of (distributed simulation, radio communications and tactical data link) interoperability standards that should be very similar to the interoperability standards used by the USAF DMO Program, systems that are compliant with the recommended ADF Corporate Synthetic Range Interoperability Model (and the Net Warrior Synthetic Range Interoperability Model) should then also be highly interoperable with USAF DMO compliant simulation systems.

The DSTO Net Warrior initiative is currently managed by AOD. DSTO LVC systems from other DSTO Divisions also participate in Net Warrior activities. However Net Warrior is not a task and does not have any direct control of any resources (manpower or funding) of its own. Net Warrior activities are resourced by voluntary contributions from individual DSTO Divisional tasks.

Discussions are now occurring to progress Net Warrior towards becoming a multi-Divisional DSTO task sponsored by multiple sponsors.

11.3 Moving Forward

Both the proposed AOD MTC CCD and Net Warrior programmes should be *natural* sponsors, developers, consumers and testers of the DSTO developed corporate LVC interoperability standards.

All AOD MTC CCD and Net Warrior LVC systems should be compliant with AOD developed Corporate LVC interoperability standards. As soon as these interoperability standards have been developed a set of Test and Acceptance (T&A) compliance procedures, which should be considered as part of the AOD Corporate, LVC, Synthetic Range Interoperability Model, should also be developed.

The AOD developed ADGESIM and DACS systems may already be fully compliant with the Synthetic Range Interoperability Model shown in Table 3 - certainly at the DIS PDU level. Once the AOD Corporate, Test and Acceptance (T&A) compliance procedures have been developed the ADGESIM and DACS systems should be "tested and accepted" (ie accredited) against the AOD Corporate, LVC interoperability standards.

Initial testing may require modification of some of the interoperability standards which will then require modification of the corresponding T&A procedures, etc. The interoperability standards and the corresponding T&A procedures would need to be reviewed, and possibly amended, regularly. However when all the required interoperability standards, and their corresponding T&A procedures, become stable they can be turned into RFT specifications by appropriate ADF acquisition staff (eg DMO or Directorate Aerospace Simulators and Special Purpose Aircraft) and eventually be used when specifying ADF systems requiring LVC interoperability. This acquisition process is an additional process that assists moving from **reducing risk towards guaranteeing interoperability** for acquired ADF LVC systems.

11.4 Section Summary

According to the LVCAR Study precepts 2 and 4 interoperability work should be centrally managed and appropriately funded to prevent divergence, and to influence LVC architecture development activities, via funding decisions, on the organisations that evolve existing architectures. Otherwise existing architecture communities will operate in line with their own self-interests; the broader corporate LVC interoperability needs of the organisation will be treated as secondary issues that are likely to continue to be ignored as concerns that are not relevant to higher priority, locally funded problems; and corporate interoperability development may only occur, if at all, in an unsatisfactory ad-hoc fashion.

In AOD the proposed AOD DMO compliant, Mission Training Centre, Capability Concept Demonstrator [Zalcman (2010)], comprising the AOD ADGESIM, DACS and AEW&C WIRE systems, and the DSTO Net Warrior initiative [Filippidis] could both contribute to the development of ADF/RAAF corporate interoperability standards.

However both these programmes must be appropriately resourced and funded (as DSTO tasks), and corporate interoperability must be made a high priority.

Both programmes (ie DSTO Tasks) would be *natural* sponsors, developers, consumers and testers of the DSTO developed, Corporate LVC interoperability standards arising from their work.

The AOD developed ADGESIM and DACS systems may already be fully compliant with the recommended corporate ADF Synthetic Range Interoperability Model - certainly at the DIS

PDU level. The AEW&C WIRE system is currently being analysed to see if it can be made compliant with the recommended corporate ADF Synthetic Range Interoperability Model.

Once an appropriate set of corporate LVC interoperability standards has been developed, a corresponding set of Test and Acceptance (T&A) compliance procedures will also need to be developed. The ADGESIM and DACS systems should then be "tested and accepted" (ie accredited) against the AOD Corporate, LVC interoperability standards using the developed Test and Acceptance (T&A) compliance procedures.

Experimental exercises should be carried out using accredited systems to see if interoperability problems are reduced. This interoperability standards development cycle should continue until a "stable level" of interoperability has been achieved.

A set of RFT specifications, that could be used to specify ADF systems requiring LVC interoperability, could then be developed. This process would then hopefully move the ADF from **reducing risk towards guaranteeing interoperability** for acquired ADF LVC systems.

12. Conclusions

Integrating the lessons learned and the recommendations from the recently released US DoD LVCAR Study [LVCAR – 1], [LVCAR – 2] with work already done [Zalcman (2010)] in the development of the Concept of the Synthetic Range and its associated Synthetic Range Interoperability Model, has enabled an (ie this) ADF LVC interoperability strategy to be developed.

The Live-Virtual-Constructive Architecture Roadmap (LVCAR) is intended to guide actions and decision-making on the development, employment and integration of US DoD LVC environments and architectures over the next 10 years.

The purpose of the LVCAR Study (phase 1 of the LVCAR) was to develop a future vision and supporting strategy to achieve significant interoperability improvements in LVC simulation environments.

To support the implementation of this strategy the LVCAR study specifies near-, mid-, and long-term actions that collectively delineate a roadmap that begins to guide the evolution from the current state of LVC environment development to achieve the desired future vision. However in such a complex environment, mid-course adjustments would be expected.

The US DoD LVCAR Study activities are designed to enhance interoperability in a mixed-architecture environment, while preserving options and positioning the community for some degree of architecture convergence in the future. These activities are founded on the idea that having multiple architectures available for use is desirable and that the best way forward is to take actions that can reduce or eliminate the barriers to interoperability between the existing architectures and protocols.

More specifically, this strategy acknowledges that existing architectures have been created, have evolved, and are being maintained to meet the specific needs of their constituent communities. Elimination of any architecture should only occur as a natural result of disuse.

Modification and management of the existing architectures is left to the owning communities as the best option to ensure meeting the needs of the various user communities, both throughout the DoD and amongst coalition partners. To resolve interoperability problems, efforts should be directed towards creating and providing standard resources, such as common gateways and tools, common componentised object models, and common federation agreements. These can resolve the problems identified and render integration of the multiple architectures an efficient and nearly transparent process by creating the perception of a single architecture that supports all of the diverse simulation systems. Thus, the systems will actually be serviced by an "architecture of architectures", comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

The presence of multiple protocols/architectures and the (incorrect) perception that interoperability would be much easier (and less costly) if only a single architecture were available has been discussed.

The four fundamental precepts (core principles) developed by the LVCAR Study that should be applicable to the ADF are:

- **Do No Harm** – No immediate action to discontinue any of the existing simulation architectures should be taken. Rather, as the differences among the architectures are gradually reduced, it should be the users themselves who decide if and when it is appropriate to merge their architectures into some smaller set based on both technical and business concerns. Any attempt to mandate a convergence solution on an unwilling user base is certain to meet strong resistance and likely to fail. **This is obviously the lesson learned by the US DoD from its attempt to mandate HLA!**

- **Start with Small Steps** - The DoD should take immediate action to improve interoperability among simulation architectures. LVC users need near-term solutions (improved gateways/ bridges, common object models, and common development/execution processes) that reduce both cost and technical risk until architecture convergence (over many years) can occur. These solutions may be low cost, and provide significant near- and midterm value to the LVC community;

- **LVC Interoperability is not free** - There are no Net Warrior, DSTO, or ADF corporate interoperability standards such as those being discussed in this report! Investments to enable the activities described in the US DoD LVC Roadmap (and discussed in this report) need to be made. The Roadmap has taken a long-term approach which requires only limited investment early in its implementation, with subsequent investments dependent on demonstrable progress. However without these necessary investments, the LVC Roadmap is nothing more than a blueprint of what it is possible to accomplish, with no mechanism to realise the associated benefits; and

- **Provide Central Management** – A centralised management structure that can perform wide oversight of M&S resources and activities across developer and user organisations to prevent divergence and enable the architecture convergence strategy, must be established. This team needs to have considerable influence on funding decisions related to future LVC architecture development activities. Otherwise existing architecture communities will continue to treat corporate requirements as secondary issues that are likely to be ignored as concerns that are not relevant to higher priority, locally funded problems; and corporate interoperability development may only occur, if at all, in an unsatisfactory (possibly counter productive) ad-hoc fashion. Interoperability needs to be appropriately tasked, resourced and developed to initially reduce risk; but then move from reducing risk towards **"Guaranteeing Interoperability"** which is far more difficult to achieve!

A set of five potential strategies were identified and investigated by the LVCAR Study:

- **Status Quo or "Do Nothing"**;
- **Actively Manage the Existing Architectures**;
- **Convergence**;
- **Select One of the Existing Architectures**; and
- **Develop A New Architecture**.

The LVCAR Study recommended two of these strategies:

- **Actively Manage the Existing Architectures** - Create standard inter-architecture integration solutions. Keep the current multiple architectures but invest in improving the construction / performance / integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper."; and
- **Convergence** - Create policy and procedures, and provide small amounts of seed money, to encourage the architectures to converge with one another in the long term time frame (e.g., 10 years). When they become so similar in features and capabilities, engineer the merging of them into a single architecture.

The LVCAR Study also recommended a set of interoperability-enhancing activities that include:

- Devise common components of architecture-independent object models;
- Produce common gateways and bridges;
- Create a common, reusable federation agreement template;
- Describe and document a common, architecture-independent systems engineering process;
- Develop and / or use common tools;
- Implement a process to maintain specifications for current and future requirements; and
- Facilitate pre-integration systems readiness (ie use a standards based approach).

In the US there are at least five different Advanced Distributed Simulation protocols/architectures in use - DIS, HLA, TENA, ALSP and CTIA. However in Australia, although there may be some use of the minor architectures (mainly in COTS systems), the vast majority of distributed simulation systems are DIS or HLA systems where according to the LVCAR Study [LVCAR – 1], [LVCAR – 2]:

- DIS (Distributed Interactive Simulation) has a comparatively low barrier to entry, and it is relatively simple to learn and easy to use. Also, it imposes a very low overhead. Whenever simulation events do not require using more advanced architectural services (such as time management, region-based information filtering, and so on), DIS offers a very economical solution to the system intercommunication problem; and

- HLA (High Level Architecture) can serve a disparate collection of simulation systems, including those that require advanced architectural services and those that have modest requirements. In addition to its large U.S. user base, its standing as an international standard has resulted in a large level of use in the coalition partner countries, facilitating combined simulation events that include multiple nations.

However, again according to the LVCAR Study

> *"DIS should only be considered as a candidate for limited convergence. This protocol provides unique services and capabilities that would be lost were the protocol to be fully converged with other architectures that serve different communities and necessarily provide higher levels of service capability. While some of the activities that could lead to more service-level compatibility (e.g., common, components of object models, standard wire-level protocols, etc.) between DIS and the other architectures will prove advantageous, **<u>DIS should remain much as it is today</u>**, a lightweight, core capability protocol";*

Therefore, because the vast majority of Australian LVC systems are DIS or HLA, and ***<u>DIS should remain much as it is today</u>***, the US LVCAR **Convergence** strategy cannot really apply in Australia. DIS and HLA will simply remain as two separate architectures / protocols and both will have to be supported.

However the LVCAR **Actively Manage the Existing Architectures** strategy "to invest in improving the construction / performance / integration of various gateways, translators, object models, and create processes and procedures to make inter-architecture integration "faster, easier, cheaper" can apply in Australia.

This current report focuses on the common object model component of the **Actively Manage the Existing Architectures** LVCAR Study strategy. Unless LVC systems have such common object models (ie common data) other LVCAR Study recommended interoperability enhancing components such gateways, translators, etc. will not work as there will be no common data for translators or gateways to work on!

The objective of this current work is to further develop an ADF Corporate Synthetic Range Interoperability Model (ie a set of ADF Corporate interoperability standards including common object models) that will precisely and unambiguously define LVC interoperability parameters that will be specified when acquiring ADF LVC systems. LVC systems that are compliant with the recommended ADF Corporate Synthetic Range Interoperability Model should be delivered and accepted (after appropriate testing) with a useful, usable level of "Out-the-Box" LVC interoperability.

The use of such an ADF Corporate Synthetic Range Interoperability Model will result in reduced cost and risk to the ADF for compliant ADF LVC systems.

Interoperability among LVC systems within a common scenario requires compliance with an agreed set of interoperability standards including network infrastructure, data, interoperability protocols, platform / environmental representation, etc. This requires the development of a Synthetic Range Interoperability Model (a set of interoperability standards) that is a crucial part of any synthetic range architecture. All LVC systems that are compliant with a particular (ie corporate ADF) Synthetic Range Interoperability Model should be highly interoperable regardless of whether the systems are Live, Virtual or Constructive.

This "Standards Based Approach" architecture will provide a high-reliability, routine, robust, scalable and reliable, global, LVC, daily training capability for the war-fighter. The USAF Distributed Mission Operations (DMO) is based on this standards based approach philosophy.

Once a Synthetic Range Interoperability Model (ie interoperability standards) has been precisely and unambiguously defined, common RFT specifications and test and acceptance procedures, to enable accreditation for that particular Synthetic Range Interoperability Model, can be developed.

LVC systems cannot participate in exercises unless appropriate accreditation has been obtained.

Compliance with a Synthetic Range Interoperability Model does not restrict additional enhancements for specific LVC systems.

All specifications defined in a Synthetic Range Interoperability Model must be mandated!

All relevant Synthetic Range Interoperability Model parameters (including the initial *Common Object Model* comprising DIS PDUs, DIS PDU data fields (or their HLA equivalents), and enumerations) must be mandated for "Out-The-Box" interoperability to be maximised.

Unless such a standards based approach (ie mandating an ADF Corporate Synthetic Range Interoperability Model) is adopted ADF LVC interoperability will be difficult to achieve!

For virtual or constructive simulation systems (ie no Live systems) the Synthetic Range Interoperability Model can be simplified further by requiring that only the SISO-J transport protocol [SISO-STD-002-2006] be supported for Link-16 Tactical Data Link interoperability. The model then reduces to that shown in Table 5 and Figure 5 where compliance with this model can be fully achieved using only DIS or HLA. In this situation specialised Tactical Data Link hardware and software is not required (or at least reduced) because SISO-J is supported in DIS or HLA thereby reducing considerably the tactical data link software and hardware (ie cost and risk) required for such systems.

The ADF Corporate Synthetic Range Interoperability Model proposed in this current report appears to be very similar (if not identical) to the Synthetic Range Interoperability Model used by the USAF.

In AOD the proposed AOD DMO compliant, Mission Training Centre, Capability Concept Demonstrator [Zalcman (2010)] (comprising the AOD ADGESIM, DACS and AEW&C WIRE systems) and the DSTO Net Warrior initiative [Filippidis] could both contribute to the development of an ADF/RAAF Synthetic Range Interoperability Model. However both these programmes must be appropriately resourced and funded, and corporate interoperability must be made a high priority.

Both these DSTO programmes would be *natural* sponsors, developers, consumers and testers of such DSTO developed, corporate LVC interoperability standards.

The AOD developed ADGESIM and DACS systems may already be fully compliant with the recommended corporate ADF Synthetic Range Interoperability Model - certainly at the DIS PDU level.

The AEW&C WIRE system is currently being analysed to see if it can be made compliant with the recommended corporate ADF Synthetic Range Interoperability Model.

Once an appropriate set of corporate LVC interoperability standards have been developed, a corresponding set of Test and Acceptance (T&A) compliance procedures will also need to be developed.

The ADGESIM and DACS systems should then be "tested and accepted" (ie accredited) against the AOD Corporate LVC interoperability standards using the associated Test and Acceptance (T&A) compliance procedures.

Experimental DMO exercises should be carried out using accredited systems to see if interoperability problems are reduced.

This interoperability standards development cycle should continue until a "stable level" of interoperability has been achieved.

A set of RFT specifications, that could be used to specify ADF systems requiring LVC interoperability, could then be developed. This process would then hopefully move the ADF from **reducing risk towards guaranteeing interoperability** for acquired ADF LVC systems.

13. Recommendations

The recommendations from this study are:

Recommendation 1: An AOD Corporate Synthetic Range Interoperability Model should continue to be developed.

Recommendation 2: The AOD Corporate Synthetic Range Interoperability Model should support both DIS and HLA (by use of the HLA RPR-FOM).

Recommendation 3: The AOD Corporate Synthetic Range Interoperability Model should include common object models; common gateways and tools; and common federation agreements.

Recommendation 4: The initial AOD Corporate Synthetic Range Interoperability Model interoperability standards should define the required common object models including DIS PDUs (already done in this report), common DIS PDU data fields, and a set of common Enumerations (future reports).

Recommendation 5: This initial set of AOD Corporate Synthetic Range Interoperability Model common object models (eg DIS PDUs for DIS) should form the basis of the common object models of an ADF (or RAAF) Corporate Synthetic Range Interoperability Model.

Recommendation 6: Once developed the common object models of an ADF (or RAAF) Corporate Synthetic Range Interoperability Model must be mandated for all ADF (or RAAF) LVC system acquisitions **otherwise ADF (RAAF) LVC interoperability will be difficult to achieve**.

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LVC Interoperability

19. ABSTRACT
Today's simulation technology allows warfighters to participate in a continuous training cycle to maintain a high state of combat readiness by using cost-effective simulation alternatives in conjunction with live-fly operations and training missions. In the USA current development of Live, Virtual, and Constructive (LVC) systems for training and mission rehearsal and the rapid advancement of networking technologies and protocol standards/architectures have contributed to a synthetic environment where multi-force Distributed Mission Operations (DMO) joint/coalition exercises have become an everyday reality.

For the ADF to participate in such a capability corporate interoperability standards, processes, common applications and databases need to be developed. This report discusses a strategy to enable the ADF to begin to progress towards such a highly interoperable, LVC synthetic environment where a first important step is the development of a suitable set of ADF corporate LVC interoperability standards.